INQUIRY-BASED LEARNING AND A DIGITAL LIBRARY IN UNDERGRADUATE SCIENCE: OPPORTUNITIES REALIZED AND CHALLENGES REMAINING

by

XORNAM SELLINA APEDOE

(Under the Direction of Thomas C. Reeves)

ABSTRACT

There is a revolution in earth science education promoting a re-conceptualization of teaching and learning in the earth sciences. Advocates for change, recommend that earth science learning experiences should include the use of inquiry based learning, and emphasize the use of Internet resources. Digital libraries, which can provide instructors and their students with access to the same data and tools commonly used by scientists, are a promising new technology that presents unique opportunities for learning in inquiry-based learning environments in the geosciences.

The focus of this dissertation research was on improving educational practices in an undergraduate geology course. This study examined the use of an inquiry-based learning curriculum, supported by use of a digital library, in an undergraduate geology laboratory. More specifically, the goals of this research were: (a) to provide a realistic description of how students engage in, and appropriate inquiry practices, (b) to explore the opportunities and obstacles presented by a digital library for supporting teaching and learning in an inquiry-based laboratory, and (c) to begin to delineate guidelines for helping instructors incorporate inquiry-based approaches in their undergraduate geoscience courses.

This interpretive qualitative study utilized a layered case-study approach that included both an analysis of one macro-level case and cross-case analyses of several individuals. The macro-level case analysis, documented the implementation of a digital library into an inquiry-based geology course. The cross-case analyses of three individuals documented students' appropriation of and participation in inquiry activities. Data collection procedures consistent with an interpretivist investigation employing qualitative methods such as direct observation, document analysis, and interviews were used to help address the research questions of interest.

Results from this study suggest that although students were able to successfully engage and appropriate inquiry practices (e.g., giving priority to evidence), it was not without its challenges (e.g., a perceived lack of guidance). In addition, although both the instructor and students recognized a number of opportunities presented by digital libraries for supporting teaching and learning, they encountered a number of obstacles in their use of the digital library that discouraged them from taking advantage of the resources available.

INDEX WORDS: Inquiry-based Learning; Undergraduate Science; Digital Libraries

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To laugh often and much; to win the respect of intelligent people and the affection of children; to earn the appreciation of honest critics and the betrayal of false friends; to appreciate beauty; to find the best in others; to leave the world a bit better, whether by a healthy child, a garden patch, or a redeemed social condition; to know even one life has breathed easier because you have lived…this is to have succeeded!"

~ Ralph Waldo Emerson~

The completion of this dissertation is a task that I could not have completed if it were not for the support and guidance I received from a number of people. Firstly, I would like to extend my most sincere thanks and appreciation to my major professor, Dr. Thomas Reeves, without whom, I never would have embarked on this journey here at UGA. I am grateful for his support, encouragement and belief in my potential. I would also like to express my heartfelt thanks to my committee members: Dr. Michael Hannafin, Dr. Janette Hill, and Dr. Jodi Holschuh, who have each supported me, both personally and academically in ways too numerous to recount here.

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Finally, to all the great friends I have made during my time at UGA, (you know who you are!), – you have definitely helped me 'laugh often and much' - and for that, I am immensely thankful. You have all made my experience here at UGA and in the USA one worth remembering! And to my family and friends 'back home' who have given me such unconditional love and support, and challenged me to go off and explore and experience life 'south of the border,' – thank you – it has meant more to me than you could ever know.

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PROLOGUE

> *The faculty member of the 21st century university could thus become more of a consultant or a coach than a teacher, less concerned with transmitting intellectual content directly than with inspiring, motivating, and managing an active learning process. That is, faculty may come to interact with undergraduates in ways that resemble how they interact with their doctoral students today.*
>
> *(National Research Council, 2002, p. 26)*

Researcher's Perspective

If anyone had told me when I began graduate school at The University of Georgia that I would be conducting my dissertation research on student learning supported by use of a digital library in an undergraduate geology classroom, I would have told them that they were crazy. In fact, it was not until about two years ago that I first heard the term 'digital library,' and subsequently became interested in its uses and facets. In addition, although the geosciences are an area of study with which I have had some prior exposure as an undergraduate, it was not an area that I was particularly interested in at the time.

Now four years later, here I am, numerous courses, several related research experiences in the Learning and Performance Support Laboratory, and one long dissertation later, and I have become deeply immersed in the literature about science learning, teaching in the geosciences, and digital libraries. In retrospect, I can see how this dissertation represents a line of research that I have been pursuing since I embarked on a research career while completing my undergraduate honors thesis at the University of Alberta. While working with my undergraduate honors advisor Dr. Connie Varnhagen, I became interested in the use of technology to support student learning in large lecture classes. At the time, Dr. Varnhagen had designed and developed an innovative introductory psychology class that combined use of online group discussions with face-to-face lecture. Dr. Varnhagen's use of Web-based technologies to create a richer, more engaging, and personal learning experience for the 100 students enrolled in her course, sparked my interest in the use of technology in higher education. As an undergraduate, I had too often been subjected to the large lecture class in which I was just another face in the crowd, expected to regurgitate the instructor's lecture notes on a multiple-choice exam, and rarely required to engage in deep thinking. Thus for my undergraduate honors thesis, I conducted a study which examined the evolution of students' critical thinking as a function of participation in this innovative introductory psychology course.

Working with Dr. Varnhagen I learned two important lessons. The first lesson I learned was that university courses could be so much more than large lectures with multiple-choice exams, and moreover that, with the appropriate pedagogical design, technology could be used to create a learning experience that was engaging, thought-provoking, and challenging for students. The second lesson that I learned from Dr. Varnhagen was that none of this is possible without an instructor who cares enough to put in the time and effort to create such a learning environment. Based on this early research and development experience, I also came to recognize that it requires a significant amount of time and effort for both the instructor and students to implement pedagogical change effectively.

My interest in students' ability to think critically, the design of learning environments that encourage students to be active and thoughtful learners, and the use of technology to support student learning, still remains strong. This dissertation describes the result of a study in which, as a researcher, I was given the opportunity to work collaboratively with a geology professor to re-design the laboratory component of her undergraduate geology course to incorporate an inquiry-based pedagogy, supported by use of a digital library. Thus I was able to pursue my interest in designing engaging learning environments that support the development of students' critical thinking skills, all supported by the use of technology.

In addition, this dissertation describes the results of the efforts of a geology professor who displays the same passion and drive for teaching and her students' learning that Dr. Varnhagen demonstrated. This professor was willing to embark on a journey in which she had to embrace innovative teaching strategies, incorporate new technology, and open up her classroom for scrutiny by me as an external researcher. This professor put in an extraordinary amount of time and effort to make her course a success, and from the results of the study it appears she was aptly rewarded.

Background for the Study

> *In the 21st century, curricula must reflect new learning strategies and technologies. Curricula should move away from the passive reading of textbooks to dynamic pedagogical approaches that support authentic student investigations and the development of skills of inquiry, exploration and discovery. (p. 33)*
>
> *(Barstow & Geary, 2002*)

There is a revolution in earth science education promoting a re-conceptualization of teaching and learning in the earth sciences. *Blueprint for Change: A Report from The National Conference on the Revolution in Earth and Space Science Education* (Barstow & Geary, 2002), details a new vision for earth science education. Earth science educational experiences should help students develop thinking skills such as inquiry, visual literacy, understanding of systems and models and the ability to apply knowledge and problem solving to a range of substantive, real-world issues (Barstow & Geary, 2002). To accomplish such understanding and thinking skills, *Blueprint for Change*, recommends that student learning experiences should encompass and emphasize: (a) inquiry-based learning, (b) use of visualization technologies, and (c) understanding of earth as a system (Barstow & Geary, 2002).

Inquiry-based Learning

There has been a renewed interest in the use of inquiry-based learning in science classrooms at all grade levels since the National Research Council (NRC) released the National Science Education Standards (NSES) nearly a decade ago (National Research Council, 1996). The NSES reject the traditional emphasis on memorization and recitation of facts in science, rather they call for inquiry to play a significant role in science teaching and learning (Edelson, 2001). Inquiry describes the "diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" (National Research Council, 1996, p.23). Inquiry also refers to the learning activities of students "in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (National Research Council, 1996, p. 23). Thus inquiry describes both a process that scientists use to investigate phenomena in the natural world, as well as an instructional methodology that can help students achieve understanding of scientific concepts by participating in research activities typical of working scientists.

To date, research on inquiry-based learning has focused on demonstrating the benefits of inquiry for the development of students' cognitive abilities such as critical thinking, scientific reasoning, and understanding of scientific concepts. However, with the current emphasis on learning not only scientific knowledge, but also the processes and procedures that produced such knowledge (inquiry), educational researchers have become increasingly interested in students' understanding and ability to appropriate scientific inquiry practices (Kanari & Millar, 2004). It is important that we know what is being done, and how it is being done, when students are engaged in inquiry activities (Wheeler, 2000), so that we can develop guidelines for successfully incorporating inquiry activities into classrooms at all educational levels.

Despite their best intentions, higher education earth science instructors seeking to implement inquiry-based learning may falter when they attempt to assemble the resources needed to provide their students with access to dynamic scientific data. This is where digital libraries such as the Digital Library for Earth Systems Education (DLESE) come into play. Digital libraries, which can provide instructors and their students with access to the same data and tools commonly used by scientists, are a promising new technology that presents unique opportunities for learning in inquiry-based learning environments.

Although it is easy to view digital libraries as merely another source of information, digital libraries (such as DLESE) are more appropriately viewed as powerful resources that can provide new opportunities to engage students in inquiry-based science (Edelson & Gordin, 1996). Digital libraries can support inquiry-based learning in undergraduate science courses by providing access to resources that (a) enable students to investigate authentic scientific questions using real data, (b) help students develop a view of science as inquiry, and (c) provide a common ground linking students with a community of practicing scientists (Edelson & Gordin, 1996). With the significant investment of funding and research that has gone into creating usable digital libraries, including many millions of dollars from the National Science Foundation in the USA alone, it is imperative that educational researchers examine the ways in which digital libraries can, and are, being used in classroom settings.

The focus of this dissertation research was on improving educational practices in an undergraduate geology course. This study examined the use of an inquiry-based learning curriculum implemented in the laboratory portion of an undergraduate geology course and supported by use of a digital library. More specifically, the goals of this research were: (a) to provide a realistic description of how students engage in, and appropriate inquiry practices, (b) to explore the opportunities and obstacles presented by a digital library for supporting teaching and learning in an inquiry-based classroom, and (c) to begin to delineate guidelines for helping instructors incorporate inquiry-based approaches in their undergraduate geosciences courses.

Research Design

This interpretive qualitative study utilized a layered case-study approach that included both an analysis of one macro-level case and cross-case analyses of several individuals (Patton, 2002). The macro-level case analysis, in which the unit of analysis was the undergraduate geology course, documented the implementation of a digital library within an inquiry-based geology course. The cross-case analyses of three individuals documented students' appropriation of and participation in inquiry activities within that same course. Data collection procedures consistent with an interpretivist investigation employing qualitative methods, specifically direct observation, document analysis, and interviews, were used to help address the research questions of interest.

The research design used in this study was well aligned with the purposes and focus of development research (van den Akker, 1999). Development or design-based research (Kelly, 2003) is focused on creating innovative approaches to address problems in human teaching, learning or performance while at the same time the research is focused on constructing a set of design principles that can guide future development efforts for addressing similar problems (van den Akker, 1999). Unlike traditional research models in which design is often used as a strategy for testing or evaluating theories, in design research, design plays a crucial role in the development of theories (Edelson, 2002). Thus, along with the aforementioned goals of this research, constructing a set of design principles that can be used to create similar learning environments in other undergraduate geology courses was a primary goal of this research. Of course, most design-based research studies last for years, taking innovations through multiple iterations of problem identification, prototype design, testing, identification of design principles, redesign, and so forth. This study represents just one iteration of an on-going research project.

The Manuscripts

The primary reports of my research are presented as four research manuscripts ready for submission to refereed research journals. The first paper (Chapter 2 in the dissertation), *Inquiry-based Learning and Digital Libraries in Undergraduate Geosciences Education: Opportunities Realized and Challenges Unmet*, presents the conceptual framework in which the research is situated. The purpose of this paper was twofold: to explore rationales for integrating inquiry-based learning into postsecondary science education, and to propose that digital libraries are technological tools that can support inquiry-based learning goals in undergraduate science courses. The target journal for this manuscript is the *Journal of Science Education and Technology.*

The second paper (Chapter 3 in the dissertation), *Investigating the Use of a Digital Library in an Inquiry-based Undergraduate Geology Course: Opportunities Provided and Obstacles Encountered*, reports findings from the research study that investigated the opportunities and obstacles presented by a digital library for supporting teaching and learning in an inquiry-based undergraduate geology course. Recommendations for developers of digital libraries, as well as for instructors wishing to integrate use of a digital library for supporting their teaching and student learning in an inquiry-based course, are also presented. The target journal for this manuscript is the *International Journal of Science Education.*

The third paper (Chapter 4 in the dissertation), *Student Engagement in Inquiry-based Learning in an Undergraduate Geology Course*, describes the results of the study aimed at illuminating three individual students' learning experiences within the inquiry-based learning environment. This paper reports the synthesis of three case studies of students' engagement in inquiry-based learning activities in an undergraduate geology course. Details of how students engaged in scientific questions, gave priority to evidence, formulated explanations, evaluated explanations, and communicated and justified their findings are presented. A goal of this research has been to describe realistically what college students do, and where they experience challenges, when engaged in inquiry activities. The target journal for this manuscript is the *Journal of Research in Science Teaching.*

The final paper (Chapter 5 in the dissertation), *Integrating Inquiry-Based Learning into an Undergraduate Geology Course: Guidelines and Lessons Learned,* describes the practical implications of the research findings for geology instructors and science educators. The purpose of this paper is to provide guidelines for integrating inquiry-based learning into an undergraduate geology course, based on the lessons learned from the overall research experience. The target journal for this manuscript is the *Journal of Geoscience Education.*

Is this an Instructional Technology Dissertation?

One of the advantages of being a researcher in the field of instructional technology is that it provides one with the opportunity to engage in research in a wide variety of disciplinary areas. Multiple theories and research traditions from disciplines such as communications, systems, psychology, and media are integral to the field of instructional technology, helping to shape current thought about the effective integration and application of technology to a wide variety of teaching and learning environments. This dissertation documents the results of applying theories and principles integral to the field of instructional technology to the design, development and implementation of an undergraduate geology learning experience. Some might argue that research may appear equally suited for the science education community, and I would not disagree too strongly. After all, all four manuscripts are being submitted to journals that are primarily related to science education. However, as an instructional technologist, I conducted the study with the intention that the results of this study would also contribute back to the instructional technology literature related to the design and development of effective undergraduate learning environments.

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CHAPTER 2

INQUIRY-BASED LEARNING AND DIGITAL LIBRARIES IN UNDERGRADUATE GEOSCIENCES EDUCATION: OPPORTUNITIES REALIZED AND CHALLENGES UNMET[1]

[1] Apedoe, X. S. and Reeves, T. C. To be submitted to the *Journal of Science Education and Technology*

Abstract

The purpose of this paper is twofold: to describe robust rationales for integrating inquiry-based learning into postsecondary science education, and to propose that digital libraries are potentially powerful technological tools that can support inquiry-based learning goals in undergraduate science courses. Overviews of constructivism and situated cognition are provided with regard to how these two theoretical perspectives have influenced current science education reform movements, especially those that involve inquiry-based learning. Specific recommendations for integrating digital libraries into inquiry-based learning environments are offered, using earth science education as a context. The importance of alignment among the critical pedagogical dimensions of the inquiry-based pedagogical framework, are stressed in the paper.

Inquiry-based Learning and Digital Libraries in Undergraduate Geosciences Education

> *Earth and space science education is undergoing a revolution that is reshaping the nature and content of what is taught—with an increased emphasis on Earth as a system and expanded use of Internet resources. Students at all grade levels have greater opportunities to learn through inquiry, exploration and discovery, aided by expanded use of the Internet and visualization technology.*
>
> *(Barstow & Geary, 2002, p. 12)*

Introduction

Science enacted in formal educational settings has traditionally adopted what Yore, Florence, Pearson and Weaver (2002) have described as the 'science as a noun' perspective which "stress[es] encyclopedic volumes of knowledge and lists of procedures and processes about science" (p. 5). Regardless of the level of education, science instruction typically focuses on covering content from a textbook and exposing students to an abundance of facts, but rarely engaging students in the process of science (National Research Council, 1996b). Educational researchers generally agree that the superficial coverage of scientific concepts and an overemphasis on the teaching of facts occurs far too much in science education (Bransford, Brown, & Cocking, 2000).

There are at least two serious consequences of adopting the 'science as a noun' approach in science education. First, students develop false beliefs about the nature of science, believing that: a) science re-describes an event or phenomenon, b) an authority figure warrants what can be considered scientific knowledge, and c) scientific knowledge is only acquired through an empirical process (Qian & Alvermann, 2000). Second, students taught science this way are prone to either develop or maintain strong misconceptions about science-related concepts. Much research has shown that even after painstaking instruction that addresses common fallacies, students are prone to hold onto their misconceptions (Alexander, 1998).

Members of the K-12 science education community generally recognize that the 'science as a noun' approach has not been effective at teaching the skills and knowledge they desire and expect from students (National Research Council, 1996a). Unfortunately, the serious flaws inherent in this approach to science instruction are not as widely acknowledged within the population of professors and graduate teaching assistants who teach the bulk of undergraduate science courses, including courses intended for majors and non-majors alike (National Research Council, 1997). Ironically, these same instructors frequently complain about the inability of their undergraduate science students to connect their formal learning to real world situations (Fraser & Deane, 1999).

There is a pedagogical alternative to the 'science as a noun' approach. Inquiry-based learning approaches go beyond the teaching of basic facts, and "demands a set of teaching practices quite different from typical didactic science instruction" (Sandoval & Daniszewski, 2004, p.161). Since the release of the National Science Education Standards (NSES) (National Research Council, 1996a), inquiry-based learning approaches have been the focus of renewed interest for science educators and researchers. Although the NSES were aimed specifically at K-12 students and teachers, the recommendations contained in the reforms can be generalized to college science teaching (McIntosh, 2000).

In light of the widely acknowledged weaknesses in undergraduate science teaching (National Research Council, 1997), the purpose of this paper is twofold: first, to explore the rationales for integrating inquiry-based learning into undergraduate science education, with a special focus on earth science education, and second, to propose digital libraries as a powerful technological tool that can support inquiry-based learning goals in undergraduate earth science. The paper is divided into four primary sections. The first section deals with two theoretical perspectives, specifically constructivism and situated cognition, that have informed current rationales for re-conceptualizing the goals and methods of undergraduate science education. The second section briefly describes various rationales for integrating the teaching strategy known as inquiry-based learning into undergraduate science education. The third section suggests ways in which digital libraries may be used to support the re-conceptualized goals and methods of postsecondary science education. Finally, recommendations for meeting the challenge of aligning digital library resources with the other major components of an undergraduate science course are presented at the end of the paper, using earth science education as an example.

Theoretical Frameworks for Re-conceptualizing Undergraduate Science Education

> *There is no doubt that constructivist views of learning represent the most marked psychological influence on science education in recent years, although this is more evident at the level of discourse than practice…*
>
> *(Jenkins, 2004, p. 238)*

Any discussion of the theoretical frameworks for re-conceptualizing the goals and methods of science must begin with constructivism (Fosnot, 1996). Although constructivism emphasizes the active role of the learner in making sense of information and building understanding (Hargis, 2001), there are different interpretations of how constructivism actually enables learning (Phillips, 1995). One dimension on which constructivist perspectives are divided is on whether knowledge construction is viewed as an individual process (cognitive constructivism) or as socially situated (social constructivism) (Derry, 1996).

Cognitive constructivist perspectives such as radical constructivism, long the dominant perspective in science and mathematics education communities (Derry, 1996), view the locus of knowledge as residing in the individual mind (Prawat & Floden, 1994). In radical constructivism, learning represents a process of self-organization in which the construction of cognitive schema and mental models, which mediate between the mind and world, are the end goal (Prawat, 1996). Engaging students in reflective activity is key in the structuring and restructuring of cognitive schemes (Derry, 1996). From this theoretical perspective, providing opportunities for reflective experimentation, discourse, and clarification of conceptual conflicts is ideal for learning because these activities promote processes of assimilation and accommodation, which in turn lead to the construction of new knowledge in the form of higher order schema and mental models (Derry, 1996).

A cognitive (radical) constructivist approach places great value on knowledge construction, and thus promotes the creation of learning environments in which students are engaged in "…activities involving debate, design, and modeling," and "…specific concepts and ideas tend not to be taught directly through explanation but may be 'named' as students construct them in the context of work and discussion" (Derry, 1996, p. 166). A fundamental goal of science education based on a cognitive (radical) constructivist perspective is helping students engage in reflective practices, through the use of hands-on activities, promoting the individual construction of cognitive schema and mental models that will help them develop greater understanding of the scientific concepts that they may encounter in their everyday world. As Matthews (2002) and others have complained, radical constructivists have not done an adequate job of explaining how the naming process needed to scaffold individual knowledge construction can be implemented in the classroom.

Unlike their cognitive counterparts, social constructivist theories "reject the notion that the locus of knowledge is in the individual" (Prawat, 1996, p. 217). Social constructivists contend that knowledge creation is a shared rather than an individual experience (Prawat, 1996). There are a number of different 'forms' of social constructivism perspectives, each of which has its defining characteristics and nuances (Fosnot, 1996). Sociocultural theory, based on the work of Russian psychologist Lev Vygotsky, is one of the most influential social constructivist theories in science education today (Wertsch, 1991). Sociocultural theorists were among the first to embrace the idea that knowledge is a social construct (Prawat, 1996).

However, there are differing interpretations of Vygotsky's writings, which has led to some disagreement about the exact nature of the social construction process (Prawat, 1996). According to Prawat (1996), U.S. interpreters of Vygotsky's work tend to focus on dyadic interaction in which a more knowledgeable 'other' helps a novice to build their understanding. Alternative interpretations of Vygotsky's work, place stronger emphasis on "the key role of socially developed cultural tools as mediators of intra-and intermental functioning" (Prawat, 1996, p. 218). The cultural tools referred to include psychological tools such as language, which are believed to change the nature of the actions individuals perform, ultimately helping them master their internal world of psychological processes and the external world of objects and events (Prawat, 1996). In other words, cultural tools such as language can be internalized and used for thinking, or appropriated and used to successfully complete an activity (Cobb & Yackel, 1996). From this perspective, knowledge and understanding are constructed when students engage socially in discussions and collaborative activities, appropriating the cultural tools as they are engaged in meaningful tasks (Driver, Asoko, Leach, Mortimer, & Scott, 1994).

A primary goal of science education from a social constructivist perspective is helping students develop literacy within the scientific domain so that they can understand the central ideas and patterns of discourse within the domain. A social constructivists' approach to science education would presume that "in order for students to become literate in science or any academic domain, they must learn the ideas and discourse of that domain through a variety of social interactions that balance teacher guidance with student engagement" (Maria, 2000, p. 19). The nature of the balance between student engagement and teacher guidance remains unresolved (Matthews, 2002).

In addition to constructivist views of learning, various science educators have 'discovered' situated cognition over the last fifteen years (Jenkins, 2004). Situated cognition theory (Brown, Collins, & Duguid, 1989) asserts that what is learned cannot be separated from how it is learned and used. That is, learning and cognition are fundamentally situated within a context. From a situated perspective, knowledge and "its constituent parts index the world and so are inextricably a product of the activity and situations in which they are produced"(Brown et al., 1989, p. 33). Knowledge is also viewed as a tool, which one can 'acquire' without knowing how or when to use it. But one cannot use the tool (knowledge) appropriately without learning how the culture (community) views and uses the tool. Situated cognition therefore views learning as a process of enculturation into the practices and activities of a community of practitioners. Applying the ideas of situated cognition to science education suggests that an important goal of science education should be to provide students with authentic experiences in science, helping students become familiar and proficient with the processes of scientific inquiry.

Based on the ideas of cognitive constructivism, social constructivism, and situated cognition, the vision for science education can be re-conceptualized from one that primarily encourages acquiring factual knowledge to one that encourages developing an integrated understanding of and facility with a specific scientific domain, such as earth science. From this perspective, the goal of science education should be to help students develop an understanding of the nature of science and the social language associated with the domain through participation in authentic, real-life contexts. Students should aim to master the skills, knowledge and language of the domain if they are to attain understanding of scientific concepts, the ability to participate in scientific activities and discourse, and the ability to think and reason in a diverse range of communities in which science is used. Scientists' knowledge of scientific concepts, inquiry skills and scientific tools are inextricably bound together (Edelson, Gordin, & Pea, 1999), thus the primary goal of science education should be to help students develop this same type of integrated understanding of the concepts, practices, concepts, and tools of a particular content domain such as earth science. This is no easy task.

Creating a 'New' Undergraduate Science Learning Experience

> *Teaching in ways that help students understand the nature of science and how to use scientific reasoning patterns have long been central goals of science education…However, in spite of a general and long-term philosophical commitment to these goals, the vast majority of research forces the conclusion that the goals have been largely unfulfilled…*
>
> *(Lawson, 1999, p. 401)*

Inquiry-based learning is a manifestation of educators long-term desire to make learning more meaningful, transferable, and conducive to self-directed, life-long learning (Lim, 2004). Inquiry describes the "diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" (National Research Council, 1996a, p.23). Inquiry also refers to the activities of students "in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (National Research Council, 1996a, p. 23). Thus inquiry describes both a process that scientists use to investigate phenomena in the natural world, as well as an instructional methodology that can help the acculturation of students into a scientific community while developing understanding of scientific concepts.

The process of inquiry consists of a number of activities including (National Research Council, 1996a): making observations; posing questions; examining resources such as books and other information sources to determine what is already known; planning investigations; reviewing what is known from experimental evidence; using tools to gather, analyze and interpret data; proposing answers or explanations, and making predictions; and communicating results of investigations. Scientists typically engage in these inquiry activities when pursuing greater understanding of an unfamiliar phenomenon. However, to engage in these activities one must have the ability to identify assumptions, use critical and logical thinking, and consider alternative explanations (National Research Council, 2000). Additionally, because inquiry is not a context free activity, and every academic discipline has its own language, theories and methods for conducting inquiry, learners must learn the unique language, theories and methodologies for doing inquiry in their particular discipline (Lim, 2004).

Inquiry as a teaching methodology and learning experience emphasizes providing students with opportunities to participate and practice the activities involved in inquiry, including using the language, tools, theories and methodologies associated with the particular discipline. When learners are engaged in inquiry-based learning environments they should (National Research Council, 2000):

1. Be engaged in scientifically oriented questions,
2. Give priority to evidence, allowing them to develop and evaluate explanations that address scientifically oriented questions,
3. Formulate explanations from evidence to address scientifically oriented questions,
4. Evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding, and
5. Communicate and justify their proposed explanations.

These five elements are essential characteristics of an inquiry-based learning environment. Variations in the amount of learner self-direction and direction from the teacher or learning materials characterizes each inquiry-based learning environment as more "guided" or more "open" (National Research Council, 2000). Guided inquiry and open inquiry are used to support different learning goals: "guided inquiry can best focus learning on the development of particular science concepts. More open inquiry will afford the best opportunities for cognitive development and scientific reasoning" (National Research Council, 2000, p. 30). All variations of inquiry are acceptable provided "the learning experience centers on scientifically oriented questions that engage students' thinking" (National Research Council, 2000, p. 28).

Although the National Science Education Standards (NSES) are aimed primarily at science educators at the K-12 level, the National Science Teachers Association (NSTA) believes that it is imperative that college and university science instructors recognize that they are part of, and are affected by the current reform initiatives (McIntosh, 2000). In fact the NSTA K-16 Coordination position statement states that: "Teachers of college/university science courses must integrate the principles of the National Science Education Standards into their own teaching to reinforce the comprehensive science experiences of students"

(National Science Teachers Association, 2000). More and more students are being exposed to inquiry-based learning approaches during their K-12 science education experiences, and will hopefully be entering college and university science courses with strong inquiry skills and raised expectations for being engaged in inquiry. If these inquiry-ready students do show up in college classrooms and laboratories, science instructors at the undergraduate level must begin to adapt their teaching approaches in order to meet the challenge.

Since the 1960s, inquiry-based teaching approaches have been advocated among science educators to help promote students' critical thinking, conceptual understanding and scientific reasoning abilities (Cavallo, Potter, & Rozman, 2004). A number of studies have reported the benefits of inquiry-related teaching approaches, suggesting that inquiry teaching techniques foster among other competencies, scientific literacy, understanding of scientific processes, and critical thinking (Haury, 1993). Inquiry-based learning allows students to engage with the material, build on their prior knowledge, and improve their grasp of the scientific method and its strengths and weaknesses (Keller, Allen-King, & O'Brien, 2000). Engaging in inquiry also provides students with experience in processes that characterize authentic scientific practice such as questioning, evidence gathering and analysis (Edelson, 2001). Finally, students engaged in inquiry activities are able to develop insight into the processes and methods of science, although the evidence for these deeper cognitive outcomes is weak (Sandoval, 2005).

Thus, inquiry-based learning is prescribed in the NSES as an effective pedagogical approach that science instructors at the undergraduate level can use to help students begin to connect their formal learning to real world situations. This need is especially pertinent to the geosciences. After all, higher order understanding of the earth as a system and a commitment to earth stewardship are educational outcomes that may literally determine the future of our planet.

The Role of Digital Libraries in Inquiry-based Learning Environments

> *…modeling the research process for students requires teachers to grapple with problems on the fly, make mistakes, recover, react to dead ends, and demonstrate all the other uncomfortable and frustrating aspects of problem-solving. Like Euclid, who presented the products of geometric research in the form of neat, polished deductive proofs (rather than the empirical and intuitive thought that led to the theorems), teachers are more comfortable providing polished packages/modules rather than the messy details of discovery and problem-solving. Applying digital libraries in classrooms requires different attitudes and tolerances for such learning conditions.*
>
> *(Marchionini & Maurer, 1995)*

As computer technology became more integral in scientific practice (Pagels, 1988), computers were increasingly viewed by the science education community as offering new and exciting opportunities for supporting inquiry-based learning (Edelson, Gordon, & Pea, 1999). Researchers have been exploring how technological tools such as modeling software, investigation tools, and visualization software could be used to support learning in inquiry-based learning environments for many years (Jonassen & Reeves, 1996). As illustrated by the quote from Marchionini and Maurer (1995) above, some scholars have anticipated the role and the challenges of digital libraries in inquiry-based learning activities for at least a decade.

Digital resources on the WWW can provide the opportunity for students to access an extraordinary quantity of information (Hargis, 2001), but access to information in and of itself is insufficient. Learning should be situated within the context of an authentic task to complete or complex problem to solve (Herrington & Herrington, 2005). "Learning methods that are embedded in authentic situations are not merely useful; they are essential" (Brown et al., 1989, p. 37).

When engaging in the inquiry process of information seeking to answer a question, design investigations, or interpret findings, the WWW is an obvious source of archival and dynamic information (Krajcik, 2002). Indeed, some have argued that the rapid proliferation of information on the WWW makes it necessary for students to develop more extensive information gathering skills and to become experts in learning from ill-structured resources (Fraser & Deane, 1999). Not surprisingly, one of the primary concerns that science instructors who utilize the WWW in their instruction have is that their students lack the necessary skills and attitudes to critically evaluate and use online resources (Hargis, 2001). In addition, many science instructors express concern that the seemingly infinite number of resources available on the WWW may cause information overload (Hargis, 2001).

Thus it would seem valuable to have a system or tool that would help address the concerns science instructors have about information overload on the WWW and the varying quality of online resources. Most instructors lack the time or support to subject such resources to critical evaluation themselves. Digital libraries, as organized repositories of digital artifacts and resources, have been specifically designed to alleviate some of the problems expressed by science instructors who wish to use WWW resources in their teaching (Arms, 2000).

The Digital Library Initiative began in 1994 with support from the National Science Foundation. The aim of this initiative was to "…dramatically advance the means to collect, store, and organize information in digital forms, and make it available for searching, retrieval, and processing via communication networks – all in user-friendly ways" (National Science

Foundation, 1999). A digital library, which is often used interchangeably with terms such as virtual library, online library and electronic library (Koohang, 2004), can be described as having the following elements (Association of Research Libraries, 1996):

- It is not a single entity;
- It requires technology to link the resources of many;
- The linkages between the many digital libraries and information services are transparent to the end users;
- Universal access to digital libraries and information services is a shared goal;
- The library collections are not limited to document surrogates: they extend to digital artifacts that cannot be represented or distributed in printed formats.

Wallace, Krajcik and Soloway (1996) describe several features of digital libraries that support student learning and make them significantly different from traditional libraries. Content in digital libraries is more up-to-date than that found in traditional libraries, providing students with access to the most current information to help them address the questions they may be exploring. Digital libraries may also contain information and data from primary sources that are typically used by scientists, such as images or visualization data. Unlike a traditional library, resources in a digital library may be represented in a wide variety of formats, and because information is available in a digital form, it allows for easier manipulation and use by students. In addition, digital libraries can provide students with the opportunity to create and publish their work in digital form, sharing their work with a wide audience. Finally, digital libraries can provide ready access to information all from one source, as opposed to tracking down resources from various locales (e.g., school library, public library) as may be the case when using traditional libraries. Thus the potential benefits of using digital libraries for educational purposes are great.

It must be noted that most of the features described above have a possible negative side as well. For example, the fact that digital library resources are in digital formats may encourage students to plagiarize content from unacknowledged sources. In addition, the ease-of-use of digital libraries may discourage learners from accessing traditional sources of information such as books that have not been digitized (Friedlander, 2002). As with any educational technology, digital libraries must be carefully integrated into education practice before the benefits can be maximized.

A number of digital libraries focused on different content domains have been developed as part of the Digital Library Initiative. The Digital Library for Earth Systems Education (DLESE) (http://www.dlese.org) is one such digital library that is intended to serve as a repository for resources and data specifically related to earth science. A screen capture of the home page for DLESE can be seen in Figure 2.1. DLESE is a component of the National Science Digital Library (http://nsdl.org/).

DLESE currently houses over 9,000 resources, about 45% of which are in the 19 thematic collections related to a range of topics dealing with earth science. Its features include the ability to search for resources according to: educational level (including the first two years of undergraduate school, the last two years of undergraduate school, and graduate level resources); resource type (e.g., lesson plans, visualization data, animations, and video); collections (DLESE resources that are organized by themes or other evaluative criteria, e.g., DLESE Reviewed Collection); and standards (including the National Science Education Standards and the National Geography Standards).

Once a resource of interest is found in DLESE, a summary of the resource's properties is displayed including: a brief description of the resource; resource type; subject areas addressed; and the educational level for which the resource is appropriate. Instructors and their students are also able to see others' reviews of the resource, teaching tips for using the resource in a class, and other resources related to the topic of interest.

Although it is easy to see digital libraries as merely another source of information, digital libraries such as DLESE can do much more than provide access to information and should be viewed as resources that can provide new opportunities to engage students in inquiry-based learning (Marchionini & Maurer, 1995). But just as Jenkins (2004) decried the fact that more instructors talk about constructivism than actually practice it in their teaching, the roles of digital libraries in inquiry-based learning theories remain more speculative than actual.

Aligning Critical Pedagogical Dimensions within an Inquiry-based Undergraduate Geosciences Course

> *In the 21st century, curricula must reflect new learning strategies and technologies. Curricula should move away from the passive reading of textbooks to dynamic pedagogical approaches that support authentic student investigations and the development of skills of inquiry, exploration and discovery.*
>
> *(Barstow & Geary, 2002)*

Blueprint for Change: A Report from The National Conference on the Revolution in Earth and Space Science Education (Barstow & Geary, 2002) details a new vision for earth science education that in principle represents nothing short of a revolution in teaching and learning in the earth sciences. *Blueprint for Change* advocates adopting the science as a verb perspective rather than the science as a noun perspective. Geosciences educational experiences should help students develop thinking skills such as inquiry, visual literacy, understanding of systems and models and the ability to apply knowledge and problem solving to a range of substantive, real-world issues (Barstow & Geary, 2002). To accomplish such goals, *Blueprint* *for Change* recommends that learning experiences encompass and emphasize use of inquiry-based learning and visualization technologies to promote understanding of the earth as a system.

Incorporating inquiry-based learning as the primary pedagogy and digital library resources such as dynamic data and powerful visualizations as enabling technologies into earth science education have enormous potential to foster undergraduate students' rich understanding of the nature of earth science and their acculturation into a community of earth scientists. More specifically, integrated into an inquiry-based learning environment, DLESE has the potential to serve as a key technological resource that will provide students with access to the types of tools and resources (such as visualization technologies and real-time data) that can promote the types of authentic learning experiences advocated by earth science education reformers. Digital libraries can support the creation of powerful educational experiences by providing access to resources that (a) enable students to investigate authentic scientific questions using real data, (b) support activities that help students develop a view of science as inquiry, and (c) provide a common ground linking students with a community of practicing scientists (Edelson & Gordin, 1996). However, the potential of digital libraries to support inquiry-based learning in undergraduate education will only be realized if the dimensions of the inquiry-based pedagogical strategy used are closely aligned with the resources accessible through digital libraries (Wang & Reeves, 2003).

The necessity of pedagogical alignment cannot be over-emphasized. There are multiple dimensions that must be aligned when designing and implementing any undergraduate course (Reeves, 1994). At a minimum, these dimensions include: course objectives, course content, pedagogy, task characteristics, instructors' roles, students' roles, technological affordances and assessment strategies. When an undergraduate science course that utilizes an *inquiry-based pedagogy*, infused with technology such as a digital library, is designed and implemented it is of utmost importance that the remaining seven dimensions are in alignment with the pedagogical design. A description of these seven dimensions and how these dimensions can be characterized within the context of an inquiry-based pedagogical framework follows:

- *The objectives* – the knowledge, skills and attitudes that students should develop as a result of participating in the course. Objectives are ideally stated as measurable outcomes ranging from discrete knowledge (e.g., students will be able to identify and quantify key distinguishing properties of rock formations) to higher order thinking (e.g., students will exhibit a robust mental model of the earth as a system).
- *The content* – the information and data that encompass the subject matter to be taught, studied, and learned in the course. More often than not in undergraduate science courses, content is presented in highly structured formats such as textbooks, but within an inquiry-based course, content should be accessible in ill-structured, real-world formats such as the data from remote sensing satellites. Digital libraries may help provide students with access to such ill-structured, real-world data.
- *Task dimensions* – the strategies used to engage students in meaningful learning activities. The National Survey of Student Engagement (NSSE) indicates that undergraduate students are much less engaged in learning activities known to foster academic achievement than expected by their professors (Kuh, 2003). As described above in this paper, inquiry-based learning has the potential to engage students in inductive problem-solving akin to the work of real-world scientists. Task dimensions spell out the nature of the inquiry activities that students are to complete with respect to their investigation of an authentic scientific problem. A digital library allows

instructors' to create tasks in which students are able to investigate a wide range of topics, while providing the necessary materials to support students' investigations without creating an extraordinary amount of extra work for themselves (Wallace, Krajcik & Soloway, 1996).

- *Instructor's roles* – the scaffolding (or support) functions the instructor will provide while students are engaged in realistic inquiry. Instructors accustomed to a didactic teaching mode wherein they deliver prepackaged information to students in the form of lectures and assigned readings may initially struggle with the necessity of allowing their students to grapple with the inevitable complexities of authentic inquiry tasks. They may be tempted to jump in and complete tasks for students, but they should resist this urge.
- *Students' roles* – the active cognitive, psychomotor, affective, and conative (Snow, Corno, & Jackson, 1996) interactions in which students will engage as they grapple with authentic tasks, dynamic content, co-learners, the instructor, and other components of the inquiry-based learning environment. Students accustomed to more passive roles in the college lecture hall may initially resist the active requirements of inquiry-based learning. In addition, inquiry-based learning often requires collaboration just as science in the real world requires teamwork, and those students who resist working in groups will initially express dismay at this requirement. This may be especially true for the students most often rewarded with high grades within the traditional teacher-centered pedagogy.
- *Technological affordances* – the information, data, cognitive tools, visualizations, and other interactive resources provided by digital libraries and other technologies. An affordance is the interaction possibilities posed by objects in the real world or, in the

case of digital libraries, the cyber-world. The World Wide Web as a whole may be viewed by some as the ultimate digital library, but digital libraries such as DLESE have been intentionally designed to support education through processes of selection and organization, including review functions for accuracy and quality.

- *Assessment strategies* – the methods used to estimate student accomplishment of the course objectives. Historically, this has been one of the weakest aspects of both traditional and innovative course design and implementation in higher education (Shipman, Aloi, & Jones, 2003). In traditional undergraduate science courses, assessment and grading are usually based upon multiple-choice tests and highly structured lab assignments. In an inquiry-based learning environment, assessment is based upon observations of student engagement and analysis of documents such as research reports. Rather than using one method such as a machine-scored multiple-choice quiz, assessment in inquiry-based learning requires the assembly and critical analysis of multiple forms of evidence that learning outcomes have been attained.

Failure to align these pedagogical dimensions will undermine the successful design and implementation of an inquiry-based pedagogy into an undergraduate science course. In addition, failure to align these dimensions with the resources available in a digital library will undermine the successful integration of a digital library into an undergraduate science course. The efficacy of any one or a few of these aspects of an inquiry-based course cannot be evaluated in isolation from the others. Alignment is essential. If the instructor states higher order outcomes for a course, every effort must be made to assess those outcomes to the most reliable, valid, and feasible manner possible. If the inquiry tasks are appropriately complex and challenging, the instructor must assemble the necessary resources to scaffold students as they strive to accomplish those tasks.

Conclusion

Digital libraries such as DLESE and the National Science Digital Library (http://nsdl.org) are well-positioned to support instructors in the Geosciences and other scientific fields who wish to design and implement inquiry-based learning strategies in their courses. Digital libraries can help instructors focus on teaching higher-order skills such as problem solving, creativity, and intellectual curiosity, not just discrete facts. Digital libraries can encourage students to construct multiple interpretations of real world data rather than simply accept the pre-packaged interpretations of data found in textbooks. Digital libraries can help instructors assume new roles as learning facilitators, coaches, guides, and even co-learners. Digital libraries can allow students to be involved in the active construction of original knowledge representations using real world data rather than the regurgitation of the knowledge representations delivered via lectures or read in textbooks. Digital library resources can help instructors to shift assessment from testing of memorized concepts to interpretation of robust mental models and higher order thinking skills.

Through its support of geosciences education reform initiatives, the National Science Foundation (NSF) in the USA has promoted the use of inquiry-based learning as a powerful alternative to traditional didactic pedagogy (Barstow & Geary, 2002). Through it support of digital library initiatives, NSF has provided free global access to rich dynamic resources needed to support the implementation of inquiry-based learning in undergraduate sciences courses (Arms, 2000). It behooves undergraduate science instructors to attempt to integrate the compelling pedagogical strategy of inquiry-based learning with the amazing affordances of today's digital libraries. The case for this educational reform is nowhere greater than in the geosciences. To do less is not only a disservice to the geosciences community, but a missed opportunity to save our planet.

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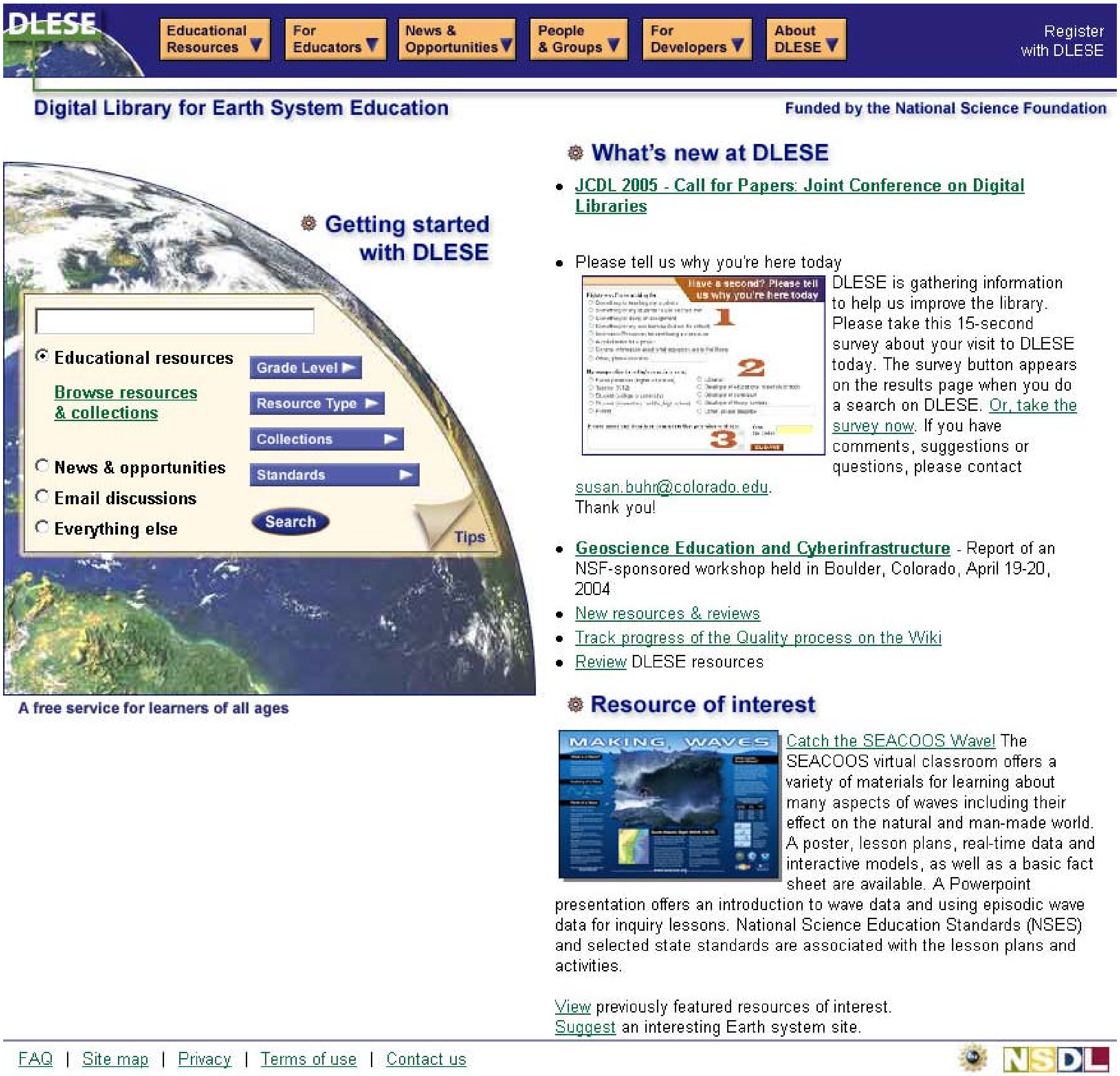
Figure Caption

Figure 2.1. Screen capture of DLESE homepage.


DLESE
Educational Resources
For Educators
News & Opportunities
People & Groups
For Developers
About DLESE
Register with DLESE
Digital Library for Earth System Education
Funded by the National Science Foundation
Getting started with DLESE
Educational resources
Browse resources & collections
Grade Level
Resource Type
Collections
Standards
News & opportunities
Email discussions
Everything else
Search
Tips
A free service for learners of all ages
What's new at DLESE
JCDL 2005 - Call for Papers: Joint Conference on Digital Libraries
Please tell us why you're here today
DLESE is gathering information to help us improve the library. Please take this 15-second survey about your visit to DLESE today. The survey button appears on the results page when you do a search on DLESE. Or, take the survey now. If you have comments, suggestions or questions, please contact susan.buhr@colorado.edu. Thank you!
Geoscience Education and Cyberinfrastructure - Report of an NSF-sponsored workshop held in Boulder, Colorado, April 19-20, 2004
New resources & reviews
Track progress of the Quality process on the Wiki
Review DLESE resources
Resource of interest
MAKING WAVES
Catch the SEACOOS Wave! The SEACOOS virtual classroom offers a variety of materials for learning about many aspects of waves including their effect on the natural and man-made world. A poster, lesson plans, real-time data and interactive models, as well as a basic fact sheet are available. A Powerpoint presentation offers an introduction to wave data and using episodic wave data for inquiry lessons. National Science Education Standards (NSES) and selected state standards are associated with the lesson plans and activities.
View previously featured resources of interest.
Suggest an interesting Earth system site.
FAQ | Site map | Privacy | Terms of use | Contact us
NSDL

CHAPTER 3

INVESTIGATING THE USE OF A DIGITAL LIBRARY IN AN INQUIRY-BASED UNDERGRADUATE GEOLOGY COURSE:[1]

[1] Apedoe, X. S. To be submitted to the *International Journal of Science Education*

Abstract

This paper reports the findings of a qualitative research study designed to investigate the opportunities and obstacles presented by a digital library for supporting teaching and learning in an inquiry-based undergraduate geology laboratory. Data for this study included classroom observations and field-notes of classroom practices, questionnaires, and audiotapes and transcripts of interviews conducted with student and instructor participants throughout the course. The results suggest that although both the instructor and students recognized a number of opportunities presented by digital libraries to support teaching and learning (e.g., provides access to various types of data), they encountered a number of obstacles in their use of the digital library used in this study (e.g., difficulty with the search mechanism) that discouraged them from taking advantage of the resources available. Recommendations for developers of digital libraries, as well as for instructors wishing to integrate use of a digital library for supporting their teaching and student learning in an inquiry-based course, are presented.

Investigating the Use of a Digital Library in an Inquiry-based Undergraduate Geology Course

Even without access to the Internet, the challenge of teaching science in our schools is not that students do not have enough access to information. The challenge is that students do not have enough opportunities to engage in scientific inquiry. Digital libraries can contribute very little to science education if they are viewed simply as another source of information for students. They can make a significant contribution if they are viewed as resources that provide new opportunities for students to engage in science.

(Edelson & Gordin, 1996, para 3)

Inquiry-Based Learning in Earth Science Education

Experts on learning have concluded that superficial coverage of scientific concepts and an over-emphasis on the teaching of isolated facts occurs far too much in science education at all levels (Bransford, Brown, & Cocking, 2000). This problem is especially evident in introductory science courses in colleges and universities where instructors typically focus on covering content from textbooks, exposing students to a plethora of facts and highly-structured problems, but rarely, if at all, engaging students in the process of scientific inquiry involving complex problems (National Research Council, 1996b).Yore, Florence, Pearson and Weaver (2002) have described this as the ‘science as a noun’ perspective which “stress[es] encyclopedic volumes of knowledge and lists of procedures and processes about science” (p. 5). Recently however, within the science education community there has been a move towards adopting a ‘science as a verb’ perspective which “emphasiz[es] the human endeavors, successes, failures, and emotional dispositions associated with doing science as inquiry” (Yore, Florence, Pearson, & Weaver, 2002, p. 5).

Inquiry-based learning is the science education community's choice of action to integrate the 'science as a verb' approach for science instruction ranging from primary school grades through graduate education. Inquiry describes the "diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" (National Research Council, 1996a, p. 23). Inquiry also refers to the activities of students "in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (National Research Council, 1996a, p. 23). Thus inquiry describes both a process that scientists use to investigate phenomena in the natural world, as well as an instructional methodology that can help students achieve understanding of scientific concepts through active participation in activities typical of working scientists.

Earth systems science represents a specific scientific domain in which the ongoing dialogue about re-conceptualizing the goals of educational programs to increase student engagement has led naturally to the promotion of inquiry-based learning. Advocates for educational reform in earth science suggest that:

> We first need to broaden the goals of instruction in Earth system science to go beyond coverage of a certain body of content. Earth system science instruction should not only incorporate genuine inquiry and hands on experience but also teach communication skills, teamwork, critical thinking, and lifelong learning skills.
>
> (American Geophysical Union, 1996, Panel 3 Discussion, para 4)

Earth science educational experiences should help students develop thinking skills such as inquiry, visual literacy, understanding of systems and models and the ability to apply knowledge and problem solving to a range of substantive, real-world issues (Barstow &

Geary, 2002). To accomplish such understanding and thinking skills, *Blueprint for Change*, a report of the 2002 National Conference on the Revolution in Earth and Space Science Education funded by the National Science Foundation in the USA, recommends that student learning experiences should encompass and emphasize: (a) inquiry-based learning, (b) use of visualization technologies, and (c) understanding of earth as a system (Barstow & Geary, 2002). Similarly, the 2003 National Academy Report, *Improving Undergraduate Instruction in Science, Technology, Engineering, and Mathematics*, stated:

> To be effective, undergraduate teaching faculty must also have at their command an aggregate of instructional strategies and be prepared to use combinations of inquiry-based, problem-solving, information-gathering, and didactic forms of instruction under appropriate classroom circumstances that promote conceptual understanding and students' ability to apply knowledge in new situations. (p. 27)

Digital Libraries in Earth Science Education

Despite their best intentions, higher education earth science instructors seeking to implement inquiry-based learning may falter when they attempt to assemble the resources needed to provide their students with access to dynamic scientific data. This is where digital libraries such as the Digital Library for Earth Systems Education (DLESE) come into play. As computer technology has become absolutely integral in most forms of scientific practice, computer technologies have also come to be viewed by the science education community as offering new and exciting opportunities for supporting inquiry-based learning (Edelson, Gordin, & Pea, 1999). The earth sciences are among the most visual of disciplines, thus it is important that instructors take advantage of new technologies when engaging students in the earth sciences (National Science Foundation, 1996). Digital libraries, such as DLESE, can be viewed as powerful resources that can provide new opportunities to engage students in inquiry-based science (Edelson & Gordin, 1996).

A digital library, which is often used interchangeably with the terms virtual library, online library and electronic library (Koohang, 2004), can be described as having the following elements (Association of Research Libraries, 1996): (a) it is not a single entity; (b) it requires technology to link the resources of many; (c) the linkages between different digital libraries and information services are transparent to the end users; (d) it attempts to provide universal access and ; (e) the library collections are not limited to document surrogates, rather they extend to digital artifacts that cannot be represented or distributed in printed formats.

Although it is easy to view digital libraries as merely another source of information, Wallace, Krajcik and Soloway (1996) describe several features of digital libraries that support student learning and makes them significantly different from traditional libraries. Firstly, content in digital libraries is current, providing students with access to the most current information to help them address the questions they may be exploring. Digital libraries may also contain information and data from primary sources that are typically used by scientists, such as images or visualization data. Unlike a traditional library, resources in a digital library may be represented in a wide variety of formats, and because information is available in a digital form, it allows for manipulation and use by students. In addition, digital libraries can provide students with the opportunity to create and publish their work in digital form, sharing their work with a wide audience. Finally, digital libraries provide ready access to information all from one organized source, as opposed to tracking down resources from various locales (e.g., school library, public library) as may be the case when using traditional libraries. Thus the potential benefits of using digital libraries in earth science education are noteworthy, especially insofar as they are capable of providing both instructors and students with unique opportunities for engaging in inquiry-based learning.

DLESE, the Digital Library for Earth Systems Education (http://www.dlese.org), is the NSF-funded digital library specifically developed to serve as a repository for resources and data related to earth science. Incorporated into an inquiry-based learning environment, DLESE is a technological resource that instructors can use to provide students with access to the types of tools (e.g., visualization technologies) and resources (e.g., real-time meteorological data) that may promote the types of learning experiences advocated by earth science education reformers. Digital libraries can support inquiry-based learning in undergraduate science courses by providing access to resources that (a) enable students to investigate authentic scientific questions using real data, (b) help students develop a view of science as inquiry, and (c) provide a common ground linking students with a community of practicing scientists (Edelson & Gordin, 1996). DLESE has been explicitly designed to provide instructors and students in the earth sciences with access to resources that can support teaching and learning in an inquiry-based learning environment.

Integrating a Digital Library into an Inquiry-based Geology Laboratory

With the significant investment of funding and research that has gone into creating usable digital libraries, it is imperative that educational researchers examine the ways in which digital libraries can, and are, being used in classroom settings. Accordingly, this paper reports the results of a qualitative investigation conducted to delineate the opportunities and challenges experienced by a geology professor and her students in utilizing a specific digital library (DLESE) to support teaching and learning in an inquiry-based undergraduate geology laboratory.

The specific purpose of this study was to characterize the opportunities and obstacles presented by a specific digital library (DLESE) for: (a) an instructor attempting to create an inquiry-based learning environment, and (b) students learning in an inquiry-based learning environment. The ultimate goal of this study is to begin to generate design guidelines for incorporating digital libraries into science instruction in higher education, and thus a detailed investigation into how a digital library was (or was not) used was an appropriate first step. The research questions of particular interest were:

1. What are the instructor's perceptions of the opportunities and obstacles presented by DLESE for supporting the teaching of an inquiry-based geology laboratory?
2. How does the instructor use DLESE to support student learning in an inquiry-based geology laboratory?
3. What opportunities or obstacles do students perceive DLESE has for supporting their learning in an inquiry-based geology laboratory?
4. How do students use DLESE to support their learning in an inquiry-based geology laboratory?

Two important factors were considered en route to defining and answering the research questions in this study. First, the features and functionality of DLESE as a tool were considered with respect to its potential to influence the ways in which both instructors and students were able to make use of this digital library for instruction and learning. Second, the ways in which DLESE was integrated into the laboratory, i.e., the nature of the learning tasks that incorporate DLESE use, were considered with respect to their potential to influence both student use of DLESE and student perceptions of the impact of DLESE on their learning.

Characterizing DLESE as a tool

DLESE (Figure 3.1) is an organized repository for resources and data specifically related to earth science. Its features include the ability to search for resources according to: grade level; resource type (e.g., lesson plans, visualization data, animations, video, etc.); collections (DLESE resources that are organized by themes or other evaluative criteria, e.g., the DLESE Reviewed Collection); and standards (including the National Science Education Standards and the National Geography Standards). Once a resource of interest is found, a summary of the resource's properties is displayed including: a brief description of the resource; resource type; subject areas addressed; and grade level for which the resource is appropriate. Users are also able to see others' reviews of the resource, teaching tips for using the resource in a class, and other resources related to the topic of interest.

The DLESE library currently houses over 9,000 resources, about 45% of which are in the 19 thematic collections related to a range of topics dealing with earth science. With respect to the types and number of resources available to both the instructor and students of the geology course that were the focus of this study, approximately 6,500 of the total resources available on DLESE were categorized as containing information relevant to the geological sciences. Please see Appendix A for a summary of the types and number of resources contained within the DLESE library.

Characterizing the learning tasks.

As part of their learning experience in the geology course investigated for this case study, students participated in both lecture and laboratory components. The lecture and laboratory components of the course were closely linked, such that the lecture topic for the week would provide some of the background knowledge necessary for students to complete their inquiry activities. The professor of the course, with assistance from the researcher, developed the inquiry tasks that students were to complete within the context of the laboratory throughout the course. Variations in the amount of learner self-direction and direction from the teacher or learning materials can be used to characterize an inquiry-based learning environment as more "guided" or "open" (National Research Council, 2000). The inquiry tasks used as part of the laboratory component of the course can be characterized as providing less direction from the instructor or materials and thus requiring more learner self-direction. Where appropriate and possible, use of DLESE was explicitly incorporated into the learning task, while in other cases, students were encouraged, but not required, to seek out additional resources and information from the DLESE site to support their inquiry. See Appendix B for an example of a learning task. Essential features and variations that characterize classroom inquiry can be viewed in Table 3.1.

Method

Context and Setting

This research was conducted in an upper-level undergraduate geology course, at a large research university in the southeastern USA. The course consisted of 2 hours of lecture and 3 hours of lab per week and focused on principles of paleobiology, including biostratigraphy, paleoecology, taphonomy, and macroevolutionary dynamics. The researcher worked collaboratively with the course instructor to re-design the activities used in the laboratory component of the course. The instructor was the primary designer of the laboratory activities, while the researcher served in a consulting role, providing feedback and suggestions for creating activities consistent with inquiry-based learning goals.

The impetus of this course redesign was two-fold. First, the instructor of the course expressed a concern about previous students' performance on her inquiry-based exams. After meeting and discussing the components and goals of her course, the instructor and the researcher determined that a re-design of the laboratory component of the course was necessary to be more consistent with inquiry-based outcomes she expected. The instructor, who was familiar with inquiry-based approaches for teaching and learning, had been utilizing inquiry-type exams, but had not frequently engaged her students in inquiry-based activities

Table 3.1

Essential Features of Classroom Inquiry and their Variations (National Research Council, 2000, p. 29)

Essential feature	Variations			
1. Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other source	Learner engages in question provided by teacher, materials, or other source
2. Learner gives priority to evidence in responding to questions	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner given data and asked to analyze	Learner given data and told how to analyze
3. Learner formulates explanations from evidence	Learner formulates explanation after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence
4. Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections	
5. Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to sharpen communication	Learner given steps and procedures for communication

More --------------Amount of Learner Self-Direction-------------Less

Less -----------Amount of Direction from Teacher or Material ---------More prior to the exams. Thus, students typically performed poorly on the exams, likely because they had very little prior experience with inquiry-based activities and had a difficult time ascertaining what was expected of them.

Second, the researcher was interested in investigating how a digital library developed specifically for the earth sciences could be used by instructors and students to support teaching and learning in an inquiry-based geoscience course. Thus, it was decided that the Digital Library for Earth Systems Education (DLESE) would be incorporated into the re-designed laboratory component of the course.

Course Description

Course Objectives. The learning goals associated with this course were for students to: (a) develop skills necessary to participate in scientific inquiry processes related to geological inquiry, and (b) develop deep understanding of the relevant geology content, (e.g., to help students learn the applied aspect of paleoenvironmental analysis and relative age-dating by using fossil organisms).

Content. The course that served as the context for this study focused on principles of paleobiology, including biostratigraphy, paleoecology, taphonomy, and macroevolutionary dynamics. Content for the course was presented in a manner consistent with inquiry-based pedagogical approaches, that is, students were given the opportunity to interact with numerous rock and fossil samples in the process of conducting scientific investigations. In addition, students were encouraged, but not required to access dynamic and static resources in a digital library specifically developed for the geosciences, the Digital Library for Earth Systems Education (DLESE – available at: http://www.dlese.org). Students also had access to more highly structured information, such as that found in their textbook or instructor provided *Paleonotes* (a type of 'cheat sheet' on many of the topics dealt with in class). Other resources used included locality maps, and pictures that often accompanied the samples presented in the lab.

Assessment strategies. In line with inquiry-based pedagogical approaches, multiple assessment strategies were used in this course, including lab reports and inquiry-based exams. See Appendix C for copies of the midterm and final exam. Final grades in the course were based upon: two in-lab quizzes; one inquiry-based midterm in-lab exam; one inquiry-based final take-home exam; one field trip research paper and presentation; one individual project; one in-lab debate; and eight lab reports.

Participant selection

Participants in the study included students, the teaching assistant, and the professor. All students were invited to participate in the study, but participation was voluntary. A total of 8 students were enrolled in the course, of which 7 students agreed to participate in the study. Student participation primarily involved completion of three questionnaires and three interviews throughout the semester. In addition to the questionnaires and interviews, student participants allowed the researcher to access copies of their completed assignments and exams, and agreed to be observed as they completed inquiry-assignments during lab time. Participation by the instructor and teaching assistant primarily involved completion of three interviews throughout the semester. In addition, the instructor provided the researcher with access to copies of all her instructional materials. See Appendix D for profiles of the 9 participants (7 students, 1 teaching assistant, and 1 instructor).

Research Approach and Data Sources

This interpretive study utilized a layered case-study approach, in which both a study of one macro-level case and case studies of several individuals (Patton, 2002) were conducted to document the implementation of a digital library into an inquiry-based geology course. The primary unit of analysis (Patton, 2002) for the analysis reported in this paper was the laboratory component of the undergraduate geology course. The results of the case studies of individual students' learning experiences in this inquiry-based geology laboratory course are reported elsewhere.

Data collection procedures consistent with an interpretivist investigation employing qualitative methods such as direct observation, document analysis, and interviews were used to help address the research questions of interest for this study. See Table 3.2 for a detailed description of the research questions and their associated sources of data.

During the implementation phase of the research both process measures and outcome measures were collected. Process measures consisted of: (a) interviews with the instructor and teaching assistant about use of DLESE, (b) student interviews and questionnaire data from students about their learning experiences and use of DLESE, and (c) observations of classroom activities involving use of DLESE. Outcome measures included instructor-created materials (e.g., inquiry assignments, worksheets, lecture notes). Further elaboration of these measures follows.

In-depth qualitative interviews in which student participants were asked to respond to a series of open-ended questions regarding issues relevant to their learning experiences, including their use and experiences with DLESE, were conducted. See Appendix E for the interview protocols used. These individual interviews were conducted outside of class at a time convenient for both the researcher and student participant, lasting approximately thirty to forty-five minutes. Students were interviewed at three different times throughout the semester, the beginning, middle and end of semester. Interviews with student participants served as a way to follow-up and gather additional information from the questionnaires that student participants completed.

Table 3.2. Summary of Data Sources

Research Questions	Method	Type of data	Analysis Method	Frequency of data collected
What are the instructor's perceptions of the opportunities and obstacles presented by DLESE for supporting the teaching of an inquiry-based geology course?	Interview	Audiotapes and transcripts	Thematic & constant comparative analysis	3
How does the instructor use DLESE to support student learning in an inquiry-based geology course?	Interview	Audiotapes and transcripts	Thematic & constant comparative analysis of interviews, observations and archival data	3
	Direct Observation	Field notes		32
	Archival Data	Lab Assignments		8
What opportunities or obstacles do students perceive DLESE has for supporting their learning in an inquiry-based geology course?	Interview	Audiotapes and transcripts	Thematic & constant comparative analysis of interviews, observations, and open-ended survey questions	3
	Questionnaire	Completed questionnaires		3
How do students use DLESE to support their learning in an inquiry-based geology course?	Direct Observation	Field notes	Thematic & constant comparative analysis of interviews, observations, and open-ended survey questions	32
	Interview	Audiotapes and transcripts		3
	Questionnaire	Completed questionnaires		3

Interviews were also conducted with the instructor and teaching assistant (once at the beginning, middle and end of semester) to gather information about their individual experiences facilitating student learning in the laboratory component of the geology course.

Questionnaires were given to participants to gauge their reaction to the inquiry-based learning activities, their experiences in the course, and their experiences using DLESE. Questionnaires, including both open-ended and close-ended questions, were administered three times throughout the semester (beginning, middle, and end of the semester), each requiring less than twenty minutes to complete. See Appendix F for the questionnaires used.

Participant observation was used throughout the semester. During every laboratory session, the researcher observed student participants working to complete their inquiry assignments. For this study, particular attention was paid to perceiving and interpreting how students were using DLESE to complete their inquiry assignments, noting any obstacles or unexpected opportunities students experienced with DLESE. The researcher recorded field notes, which were expanded and analyzed following the laboratory period in which they were collected.

Archival data such as instructor-developed assignments, lecture-notes, or worksheets were also collected as an instructor outcome measure to help characterize the instructor's use of DLESE to support learning in an inquiry-based learning environment.

Analysis

Interview transcripts were analyzed on multiple passes by the researcher (Miles & Huberman, 1994). In one pass, a thematic analysis procedure was used to analyze the interview transcripts. Thematic analysis is an inductive analysis procedure in which categories are derived from the data, that is, the specific nature of the themes and categories are not predetermined (Ezzy, 2002). Thus, the interview transcripts were explored, units of meaning were identified, codes were developed and categories and sub-categories were created (Ezzy, 2002). This process was followed until a 'master list' of codes was developed, which reflected the recurring themes and patterns in interviewees' responses (Merriam, 1998).

On a second pass, the constant comparative method of analysis (Merriam, 1998) was employed to examine interview transcripts in light of the four major research questions. This process involved examining interview transcripts, comparing codes identified on the 'master code' list, and then organizing the coded data according to each research question that it addressed.

On a third pass, the constant comparative method of analysis was used again, however this time interview transcripts were coded with respect to the interview questions. Individuals' responses to interview questions were compared across interviews to identify any themes or categories that may have been missed in during the initial two coding passes. Then the coded responses were compared across interviews to identify any new themes or categories that were specific to the interview question being addressed. The three coding passes allowed the researcher to conduct detailed, cross-coded searches for themes and categories.

A similar analysis procedure was used for coding of the open-ended questions from the questionnaire, as well the field-notes from the direct classroom observations. On the first pass of the data, a thematic analysis procedure was used to identify any categories or themes that emerged from participants' responses and behaviors. On the second pass, comparative analysis was used to code the questionnaire data and field-notes against the research questions. Questionnaire data underwent a third pass of coding, based on the questions to which the participants responded. In combination with the interview and questionnaire data, the field notes from direct classroom observations were used as a source to validate and crosscheck findings (Patton, 2002).

Results

Results are presented according to the four major research questions of interest in this study. Participants have all been given pseudonym names.

Research Question 1*: What are the instructor's perceptions of the opportunities and obstacles presented by DLESE for supporting the teaching of an inquiry-based geology laboratory?*

The greatest opportunity that Dr. Sanders believed DLESE presented for supporting teaching and learning in an inquiry-based geology course was that DLESE could serve as a portal for access to scientific information, which can sometimes be difficult to find when using a general search engine.

> *…It's all peer-reviewed, it's all scientific, umm, there's no creation science on it. That's fantastic! Because like I said, if I type in the Grand Canyon geology the first six hits let say, well I don't know right now but I remember- the first six hits are creation science, its not good science- and I can go to the DLESE site, with you know, checking the different boxes, type in the Grand Canyon and I'm going to get science. And that's the huge plus right there. And I think that's really important for the public to know about, because some people don't know the difference between creation science and science. And I think its really important that we have this service that [doesn't] have a fundamentalist Christian way of thinking out of the, of science. So that's the big plus…*

Although Dr. Sanders perceived DLESE to be a valuable service there were a number of obstacles she perceived DLESE to have with regards to supporting her teaching of an inquiry-based geology course. The two major themes that emerged from Dr. Sanders' responses were: (a) the lack of useful or relevant resources available, and (b) the functionality of the search engine.

With respect to the lack of useful resources, Dr Sanders reported that she was unable to find information that was useful to her or that would support her teaching activities in the inquiry-based geology course, and as a consequence her use of DLESE was minimal:

> *…Well I have to tell you that I tend not to use DLESE because there are a lot of things on there that I can't use and the level of information I can't really use…*

With respect to the functionality of the search engine, the inability to instantaneously find the information she was looking for presented a significant barrier to Dr. Sanders' use of DLESE. For Dr. Sanders ease of use and the amount of time required to find a resource of interest was of primary importance. Thus, Dr. Sanders was more inclined to use general web search engines such as Google when looking for material to support her teaching:

> *… If I was putting together a K-12 project, or umm, looking for, you know, information for just in general it's [DLESE] good but I have to do a lot of searching, I can't get anything instantaneously, I have to click a lot of buttons, and things like that, at least for what I've used. I use Google all the time. I just type in, I get Google up, I type in the word I want, I put a comma, I put definition and BAM it's right there! The top one, I can use.*

> *I can't do that in DLESE. Umm, DLESE takes more thought, more preparation, umm, its not instantaneous gratification. When I'm writing a lecture, you know I spend a lot of time writing lectures, but I don't have that much time…I have not used DLESE, umm, at all this semester!*

Finally, Dr. Sanders perceived the categorization of resources by different grade levels within DLESE as both a opportunity and an obstacle:

> *…The other plus is that, information is in different levels. I mean I found it as a barrier because I'd have to sift through stuff, but for most people, you could find what K-12 information is, or just K information, you could find university information. I like that a lot. I think that's great. So I could go in and find out 'oh that's kindergartener level, oh, okay' and I could learn very quickly what kindergartener level is and write something at that level…*

Although Dr. Sanders perceived DLESE to be a potentially valuable resource and service, the lack of relevant material and characteristics of the search features posed significant obstacles to her use of DLESE for supporting her teaching. Dr. Sanders reported that she was unable to make use of DLESE for her teaching activities (e.g., creating lectures) due to issues related to time and content. When asked what recommendations she had for improving DLESE for her use as an instructor, Dr. Sanders responded:

> *Yeah more substantive information in geology and paleontology, umm, probably following a historical geology framework. With pictures that professors can use, like an image bank, like done through either rock groups or by time, history by time. That would be just fabulous. I would really appreciate that. Yeah, so more of a historical geology, more of a, hmmm, time slices, and what aah, you know, the rocks, what are the rocks doing, what are the organisms doing. Have a really cool time slice all through time. And I could really use that, and that would also help us with the creation fundamentalists.*

Research Question 2: *How does the instructor use DLESE to support student learning in an inquiry-based geology course?*

Despite the many challenges Dr. Sanders found as an instructor trying to use DLESE as a resource, she was still a strong advocate for its use by her students. Dr. Sanders did a number of things to encourage her students to use DLESE to help them complete their inquiry-based assignments including: (a) listing DLESE as a resource to use on six of the eight inquiry assignments in her course, (b) frequently mentioning DLESE in class, and (c) having Internet access available during class time – with the homepage set to the DLESE website. In addition, Dr. Sanders developed a 'DLESE project,' which students completed instead of being required to complete a second mid-term exam. With this project, students were required to search DLESE to find a topic that was not well represented in the library (relating to something that had been covered in class or something they were personally interested in learning more about). Their assignment was then to develop the content for what could be turned into a web-based resource to add to DLESE. The ultimate goal of the assignment was to develop a resource that could help broaden public understanding about geology.

Dr. Sanders considered the DLESE project both a worthwhile activity for students to participate in, and believed that it was a valuable experience for students to engage in:

> *…Several students really got involved with the DLESE project and really liked the whole set up to come up with their own idea, make their own website, because they are really into technology, they are into making websites, and several people, I know Karen and Robin really got into trying to develop a substantive website with actual scientific information, really great questions, and backing it up with science…*

When asked " Do you think you'll consider doing a similar project with future students?,"

Dr. Sanders replied:

> *…Oh sure! Cause they really, the people who really did get into the project really liked it and they saw another avenue of science that they'd never explored before, which was, putting together information which they were just learning about for a DLESE website to help broaden peoples education. They didn't know that they could do that. I mean I think that was really exciting for them. Cause there's all aspects of science, you don't have to just be an academic to do science, you can facilitate science, and I think they really enjoyed that. And plus, they like working on the web and fooling around, making things look good, so I think they really enjoyed it. So yeah I definitely would do it… I think it's a really great exercise. It opens up a different avenue they never thought about before…*

Research Question 3: *What opportunities or obstacles do students perceive DLESE has for supporting their learning in an inquiry-based geology course?*

Students reported that DLESE presented a number of opportunities for supporting their learning. Two themes that emerged from student responses included: (a) the different types of data available in DLESE, and (b) the assurance of the scientific nature of resources available.

Jackson believed that, although most information could be found in his textbook, DLESE could provide access to other types of information:

> *…I mean most of the stuff you know it will be in our book pretty much other than some maps and charts and things like that will be on the website that might not be in our textbook….*

DLESE was also viewed as a source of images and graphics that could be useful for presentations and reports. For Melanie, although the information she found was below her educational level, DLESE provided her with access to useful graphics.

> *…I really only found like little kid stuff like volcanoes exploding, but it had good graphics I used in my presentation…*

In addition to providing access to different types of data or resources, students recognized the potential value of using DLESE because it provides added assurance regarding the credibility and scientific accuracy of resources found within the library. For Robin, the advantage of DLESE for some individuals would include not needing the skills to critically evaluate a web-resource, although she believed that she was quite competent in that area:

> *…But I mean I could understand why it's a good idea to have that because some people don't really know how to tell a bad webpage from a good webpage, but I've been using the Internet for school since like the 9th or 10th grade so I have a lot of experience with it so…*

Karen gave the following example of how she had encouraged others to use DLESE because of the added assurance DLESE provides that a resource found in DLESE will be scientifically accurate as opposed to a resource found using a general search engine such as Google:

> *…Yes! I tell everybody about DLESE. I was in my Surficial Processes class just now…like a couple hours ago and we had like a lab every week and umm he was like oh yeah look in these books if you know you want to look at this stuff, or look online – Google it – and I was like no – don't Google it because they could be wrong- use DLESE! And this guy behind me was like who's in the [geology] class was like 'Oh yeah thanks!'…*

There were two main themes that emerged from students' responses regarding the *obstacles* presented by DLESE for supporting their learning in the inquiry-based geology course. Much like the obstacles perceived by Dr. Sanders, students perceived both (a) the features and functionality of the DLESE search engine, and (b) the lack of relevant and appropriate resources, to be challenges in using DLESE to support their learning.

With respect to the search engine, only a few students found the search interface to be confusing or cumbersome. Robin discussed her perceptions of the challenges using DLESE, stating:

> *…I do remember going to it and trying to put something in there, the way the search is set up is kind of, it's a little confusing trying to figure, I mean, its just kind of odd. I don't know. Its just not, the user-interface I guess you can say is strange…*

Jake had similar perceptions of the user-interface of DLESE stating:

> *…The links are all just labyrinth like and it's just difficult to get at what you are looking for…*

The difficulty experienced by some students with the search features of DLESE did not appear to stem from a lack of computer literacy on the part of the students because the results from a pre-course student survey indicated that all but one student was comfortable or very comfortable using the Web. If computer skills per se were not an obstacle to student use of DLESE, weaknesses in the design of the search engine may have been a factor for those few students reporting confusion or difficulty.

A second theme that emerged from both observation data and students' responses during interviews was the lack of relevant and appropriate resources and content available on DLESE. Students either had difficulty finding resources that dealt with topics covered in the course, or finding resources that dealt with the topic at a level appropriate for a university student. Although as noted above, a few students reported that finding resources on DLESE was challenging, from observing students interactions with DLESE, most students appeared to have no difficulty navigating the digital library. The problem of finding relevant resources may lie in the search terms associated with the DLESE resources. When students entered specific scientific search terms such as "biogenicity criteria" or "komatiites" or "graptolites," they got very few or no results. When this occurred, students appeared fairly quick to either (a) give up searching, or (b) switch to Google to continue searching for the needed information.

One such example of a student who quickly switched to searching on Google after not finding what was needed on DLESE, is illustrated in the following observation:

> Start: 12:57pm
> Robin: *are you all done with this?* (to Karen - referring to the pc)
> Karen: *yes*
> Robin does search for "biogenicity criteria"
> [no results]
> Robin then searches for "fossil life criteria"
> [no results]
> Robin then searches for "life criteria"
> [Gets 2 results]
> 12:59pm
> Robin clicks on "Nova PBS site"
> 1:00pm
> Robin [closes DLESE and goes to Google]
> Searches for "biogenesity"
> [no results]
> Clicks on alternative spelling option provided "biogenicity"

[674 results]
Clicks on 1st result = http://www.astrobiology.com
1:04pm
Robin- back to Google search results
Searches for "biogenicity criteria"
[302 results]
Clicks on 1st link = spacedaily.com
1:07pm
Robin back to search results
Clicks on second link "Research" = http://users.ox.ac.uk
Robin: back to search results
Clicks on 3rd link
Back immediately to search results
Scrolls down page
Clicks on another astrobiology.com link
Back to search results
Scrolls down to end of good page
Hit next button
Clicks 1st link on 2nd page of search results = http://www.Doir.wa.gov.au
1:11pm
Robin closes websites. Closes all screens except for the Life on Mars site that Jake had left open on screen
END: 1:11pm

Jake expressed strong feelings about the navigational difficulties the DLESE site posed, and expressed what he believes the implications to be for having a poor user-interface design, or un-specific search terms associated with resources in the library:

> *…Yeah, the whole thing about DLESE is it wants to be a source for like peer reviewed, very scientific information about the earth sciences – it fails in that because people can't get that information out of the site – so that would be – before even addressing the small – I know its growing, it just started up – before even addressing the gaps in information that they have that would have to be number one…what I really know needs to be done to that site is it needs to be kind of tweaked a little bit as far as its design for it to be useful…*

Although Jake was able to find resources pertinent to his chosen topic, the level of material was not appropriate for his uses.

> *…The way they have them sorted into different age groups or like levels I guess, I find that like totally inadequate. Because like you'll get like, the file we were like looking at was Life on Mars, and its like for every age range from like grad students to kindergarten kids, so we're sitting here trying to figure out this article and we have to really like search this article to find the parts that are pertinent to like people on our level…*

When Karen initially began using DLESE she was able to find adequate resources, but as the semester went on, she states that she was unable to find exactly what she was looking for:

> *…I think I tried using it and I think once I got past a certain point in the class, like I don't know if it was too advanced or it just wasn't covered on DLESE…*
>
> *…For some things it's [DLESE] really good but for a majority of it, it's, there's a lot of stuff that's not on there. It's so hard to find exactly what you're looking for, and so many websites have, it has a little bit of yours and a lot of other stuff you know, that you are not looking for. And really there's not a lot of stuff on there, like I thought, there's a little bit, but…*

Kyle also found DLESE to be lacking in resources related to course material, although he believes this may be due to the fact that there is little information on the WWW in general about these topics:

> *…For paleontology…and for paleoecology… It just isn't there. Part of which is there just isn't a heck of a lot on the web about current viewpoints of paleontology, so its not surprising that nobody has poked it into DLESE yet…*

Thus, although students were able to recognize some of the opportunities DLESE could provide to support their learning (e.g., access to different types of data, and the credibility of information found in resources), these opportunities were not perceived as being great enough to overcome the perceived limitations of DLESE (e.g., functionality of the search engine, and lack of relevant or appropriate resources).

Research Question 4: *How do students use DLESE to support their learning in an inquiry-based geology course?*

Students' use of DLESE was directly related to their perceptions of the opportunities and obstacles of DLESE for supporting their learning. The students enrolled in this particular inquiry-based geology course found the obstacles to using DLESE to be too great to warrant any significant investment of time or energy into utilizing DLESE to support their learning. A number of rationales for not using DLESE were discussed by the students, including: (a) personal issues regarding computer use, (b) credibility issues with web resources, (c) negative experiences with DLESE, and (d) time and effort required to use web resources.

Jackson was the only student who was a self-professed anti-computer person. Thus this was one of his primary reasons for not making extensive use of DLESE

> *…I'm not a real big computer person – I try to use computers as little as possible to tell you the truth…*

Although Drake indicated that he was very comfortable and experienced with computers and WWW use, he expressed a strong critical stance towards information and resources found on the Internet:

> *…I'm very queasy on using the Internet or an online library or anything like that just because I mean my roommate showed me websites that say we never landed on the moon and stuff you know. I can't whole heartedly believe everything that is on the Internet you know, so I can use it as a good start and say I've got this question and then you type it in on the Internet and you get a couple of hits, and you're like alright I think its that, and then you like go to a book, and you find out for real…*

Other students were more receptive to using web-based resources, such as those that could be found in DLESE. However, the negative first experiences that some students had with DLESE were a deterrent to their returning to the website.

Robin's first experiences with DLESE confronted her with a search mechanism that she found confusing. The result of this experience was that she returned to using her regular search engines for finding geological information on the Web.

> *…I do remember going to it and trying to put something in there, the way the search is set up is kind of, it's a little confusing trying to figure, I mean, its just kind of odd. I don't know. Its just not, the user-interface I guess you can say is strange… you know I looked at it once and was like this is strange so I just went back to using the regular search engines. Because I'm just getting everything and its right there. So you don't have to go through all these weird categories and things so. Because you think you should just be able to type something into that search bar and get everything, but I don't know. You have to go through all of this hullabaloo to get anywhere…*

Jake expressed similar sentiments regarding his experiences with DLESE and the impact those experiences had on his subsequent use of the digital library.

> *…I let myself get so turned off from DLESE so quickly that I didn't give it as good of a chance as I should have… I uh went on there a couple times, went on there, struggled mightily, trying to find what I was going to do and then just didn't look at it again the rest of the semester. When I'm online, trying to look up stuff…its like if you are looking for something on the Internet there's no patience at all for most people at all, like because its so quick you could just be like looking somewhere else in like 10 seconds. If you can't find it like pretty readily then its like moving on, going somewhere else…*

Jake also felt that using the WWW to seek out additional information was a much too laborious process to be worth his time:

> *…So its like very, you're discouraged from going on the Internet because you get on there and you are like surfing to find something that's like pertinent and if it's pertinent 'is it scholarly at all?' and if it is, even if it is scholarly, 'is it credible?' I mean if you're going to be referencing it. So its like you're adding like, just by making your source the Internet source you're adding work…*

Alternatives to DLESE use. Although students did not make extensive use of resources found through DLESE during the semester to help support their learning and completion of inquiry-based assignments, they did make use of a number of alternative resources. Many students reported being comfortable and experienced using both computers and using the WWW. Additionally many students reported using the WWW to look up geological information, however, DLESE was not their first choice for places to look for Web-based resources to support their understanding of concepts in this inquiry-based geology course.

For example, Melanie stated that her first source for additional geological information was the Internet. When she was unable to find the information she was seeking on the Internet, she would then proceed to go to the library. However, DLESE was not her first choice of available Web resources to use.

> *…I always just go to Yahoo and just do my stuff from there I guess… I just go to the search engine. No like in particularly science locales or anything…*

[Researcher: So when you need other information how do you go about finding it?]

…I'll go to the Internet first, like it depends on what kind of information I need. If I just need a couple sentences about it just to figure out something I'll do that. But if I need like a lot of information I'll use that and I really love the library so- I still use the library a lot…

Kyle was also an avid user of the WWW for seeking out additional geology information to support his learning. However, rather than using DLESE, Kyle had compiled his own set of geological resources on the Web which he would reference when in need of information:

…over the past several years I've established the habit of using several other websites that I'm familiar with, comfortable with. One is UCMP – University of California Museum of Paleontology at UC Berkeley. One is Northern Arizona university site on tectonics. One is Adolph Silaker's own site on ichnofossils, things like that. I have a list of bookmarks in my browser that's probably got 40 items in it for major categories…Now, had I not been in the habit of using those, then, and I have looked at DLESE a bit, then yeah that would be on my, well it is near the top of my list, I'm to the point now where if I don't find it on one of my sites where I think its likely to be, then I would go look there…

Jake too had a list of favorite websites that he visited when seeking geological information:

…I use USGS a lot – that website. And I have a list of websites that I have like favorites – and I go to those for my geological information for now because I know that I can get there quickly…

Robin was also very comfortable with the WWW and computers, as well as with her skills in being able to critically evaluate a website. However, Robin's preferred choices for geological information were other people, her textbook, or Google:

…I guess I'm just used to Googling everything, its just a bad habit. That and usually if I need to find something out I can ask somebody here or its in the textbook. So I don't even use the Internet generally as a source too much because I just haven't needed it. There have been a few things that if I did I could find websites from other universities or something using search engines and so that wasn't really too big of a deal…

Karen, who was an avid user of DLESE at the beginning of the course, had switched over to using Google by the end of the course because she felt that the information she needed would not be in DLESE:

> *…And like now, like actually I just looked stuff up on the computer downstairs and I just went straight to Google. I didn't think it would be on DLESE…*

Although Jake was an experienced computer and WWW user he much preferred the textbook as his main source of additional information:

> *…I instinctively go for the book when I have a problem as opposed to the Internet. Cause usually I have the book within like arms reach and it's a lot more of a good bet, you know the book is like, I don't want to use the term peer-reviewed because that's like – its very scholarly and its like you know the information about Paleo is in the book. And you very much doubt that the teacher, Dr. Sanders especially would be giving you something that you couldn't at least find something on in the book…*

In the final analysis, the vast majority of students sought alternative sources of information and did not use DLESE to support their learning except when explicitly directed to do so as part of the inquiry-based assignment.

Implications of the Study

The main goal of this study was to ascertain the opportunities and challenges experienced by a geology professor and her students in using a digital library (DLESE) to support both teaching and learning in an inquiry-based undergraduate geology course. Both the professor and students in this case study experienced significant challenges in using DLESE to support teaching and learning in the inquiry-based learning environment. The functionality of the search mechanism proved to be cumbersome and confusing for some users. In addition, the lack of relevant or useful search results provided no impetus for users to continue to make use of DLESE. For both the professor and students, when they did make use of Web-based resources, they found it much easier to utilize traditional search engines such as Google or Yahoo to find information. Additionally, some students had already compiled an extensive list of Web-based resources that they used to gather geological information.

The results of this study have implications for both developers of digital libraries and instructors who are interested in using a digital library to support student learning in their classroom. The first lesson that can be learned by developers of digital libraries is the importance of the user interface. As Arms (2000) states: "When a system is hard to use, the users may fail to find important results, may misinterpret what they do find, or may give up in disgust believing the system is unable to help them. A digital library is only as good as the interface it provides to its users." Although, not all students experienced difficulty with the search features of DLESE, for those that did, their experience was negative enough to deter them from returning to DLESE to try to use it again. This speaks of the importance of users first experiences with a resource – for digital library developers it is of the utmost importance to ensure that the user-interface is designed so well that it will not alienate potential users. The tools for finding, managing and using digital resources must be powerful and easy to use so that students can take full advantage of the digital resources (Marchionini & Maurer, 1995). Although the developers of DLESE have done extensive usability testing, based on the results of this case study there may be usability issues that still need to be resolved.

The second issue of importance to digital library developers is the content of the library. While DLESE has promoted itself as a repository of web-based resources related to earth system science for all grade levels, clearly there are a number of topics and concepts related to geology that are not covered in the library. For a digital library to be beneficial to students, collections that are content rich and contain age-appropriate materials are needed (Wallace, Krajcik, & Soloway, 1996). It is acknowledged that the DLESE library is still growing and that resources are being added daily, but a formidable challenge that both the professor and students in this study faced was not being able to find relevant resources for their use. This brings to the fore an important issue: the importance of content coverage. As the digital library continues to grow, developers inevitably need to strike a balance between the quality of resources and the scope of resources that should be included in the library. The content topics of this course, encompassing paleobiology, biostratigraphy, paleoecology, taphonomy, and macroevolutionary dynamics, were perhaps too esoteric for the resources currently accessioned into DLESE.

One potential solution would be to focus the growth of the collection on a narrower range of education levels, or on a narrower range of topics. With respect to undergraduate earth science courses, one potentially effective strategy could be to align DLESE resources with specific pedagogical strategies, such as inquiry-based learning. Another approach might be to align DLESE resources with best-selling textbooks, but such a direction might simply reinforce traditional pedagogy rather than inquiry-based learning. These decisions should be made based on input from current regular users of DLESE. In addition, these decisions should be explicitly stated and expressed on the DLESE website, so that potential future users are clear about the focus and scope of the library, thereby reducing the level of frustration experienced by first time users.

Another potential solution would be for digital library developers to actively reach out to members of their intended audience, seeking input regarding resources and topics they would like to see covered in the library. DLESE was originally developed in response to a perceived need to improve earth science education at all levels, in both formal and informal contexts, and thus the students and professor in this case study are part of DLESE's primary target audience. Actively seeking to include resources on topics commonly covered in undergraduate geology courses would encourage and foster use of

DLESE by both students and professors in the university geology community. Special collections for specific types and levels of undergraduate courses could be developed.

Finally, library developers need to carefully review the cataloguing procedures of library resources. Digital librarians face challenges in determining the range and distinctiveness of the metadata used with resources within a library (Marchionini, 1998). It may be the case that resources in DLESE are being labeled with search terms (metadata) that are not sufficiently specific, thus contributing to the number of "no result" searches users encounter. As one student in this study, Jake, clearly stated, a digital library is ineffective in its mission to provide users to access with valuable resources if users cannot get that information out of the library because of weaknesses in the search mechanisms.

For instructors who are interested in using a digital library to support learning in an inquiry-based undergraduate classroom, a number of recommendations can be made based on the results of this case study. Firstly, the rationale for deciding to incorporate a digital library into classroom use should be considered carefully. Results from this case study suggest that students bring with them a number of perceptions and expectations related to issues such as computer use, acceptable sources of information (e.g., Web-based vs. textbook or instructor), and perhaps even more importantly, perceptions of the time and effort that should be invested into finding additional information. Students' perceptions and expectations about these and other issues can significantly affect their willingness to adopt and use technology such as a digital library to support their learning. Therefore, instructors need to be wary of making the assumption that all students are now skilled Internet users, much less members of the Millennial Generation (Howe & Strauss, 2000) who reportedly enjoy spending large amounts of time using Web-based resources. Most importantly, there is little evidence that today's college students have the critical Web-evaluation skills necessary to effectively use Web-based resources (Walton & Archer, 2004). As was the case in this study, a few students were either not comfortable with computers or were wary of the credibility of Web-based resources.

Secondly, the importance of choosing a digital library that contains resources that deal with topics that are covered throughout the course cannot be overstated. Although it seems like common sense, the assumption made at the outset of this study by both the professor and the researcher was that there would be a number of useful resources for the topics covered in class in DLESE. Unfortunately this was not the case, as the few specific resources that did deal with relevant topics were not appropriate for undergraduate students. The instructor in this course concluded that DLESE appeared to be primarily populated with resources appropriate for K-12 education. If this perception is correct, then efforts to promote DLESE usage by postsecondary instructors may be misguided. If this perception is incorrect, then mechanisms to help undergraduate instructors more easily find and align DLESE resources with their plans for inquiry-based learning activities must be provided.

Alternatively, instructors wishing to incorporate use of a particular digital library into their course may need to design the learning tasks in such a way that it requires use of the digital library for completion of the task. In this particular geology class, although DLESE was suggested as a resource to be used for completion of almost all Lab Exercises, it was only required for the completion of Lab Exercise 2. It was hoped that the mandatory use of DLESE early in the course would provide students with additional exposure to DLESE, and encourage future use. Most students reported that they made little use of DLESE after using it to complete Lab Exercise 2. Students in this case study expressed a preference for getting additional information in ways that were either most familiar to them or they perceived to require the least amount of time and effort. Thus, most students relied on their textbook, the instructor or TA, or if necessary, Web-based resources and search engines that they were already familiar with using such as Google or Yahoo.

Students are accustomed to using their textbook or asking another individual when faced with needing additional information or clarification of concepts or ideas. It is difficult for both teachers and students to move from an information giving and receiving mode to one that is primarily inquiry-based, and this change will not occur simply with access to a digital library and its resources (Wallace et al., 1996). Therefore, if an instructor wishes to lessen students' dependence on highly structured textbooks and encourage exploration of concepts and ideas using real-world Web-based resources, then one suggestion may be to make the textbook optional in the course. This way, students may purchase the text if they feel it will provide useful information, but in addition, this strategy will promote the view that a textbook is just one of many possible sources of information rather than the sole source of information for learning in the course.

Conclusion

This research examined the belief that digital libraries can provide new opportunities to engage students in inquiry-based learning. Both students and the instructor in this study encountered significant challenges, and thus the vision of a technologically supported inquiry-based learning environment was left unrealized. However, the challenges faced by both the professor and students in utilizing the digital library to support their teaching and learning has brought to the fore a number of issues that can be useful for both developers of digital libraries and instructors of inquiry-based courses.

Future research directions could include qualitative studies such as this one, which would provide a wealth of knowledge and insight into the perceptions, uses, and needs of instructors and students attempting to make use of a digital library to support their teaching and learning. This research could be based within this particular course, after refining the design of the laboratory exercises to more fully incorporate use of DLESE resources, or it could be situated within a more general (perhaps introductory level) geology course. In addition, studies that utilize different digital libraries and alternative course designs would allow researchers to begin to identify the various factors and conditions that may enable the successful integration of digital libraries into inquiry-based classroom environments. These studies are necessary if we are to begin to take advantage of the numerous affordances of digital libraries as well as the compelling pedagogical strategy of inquiry-based learning.

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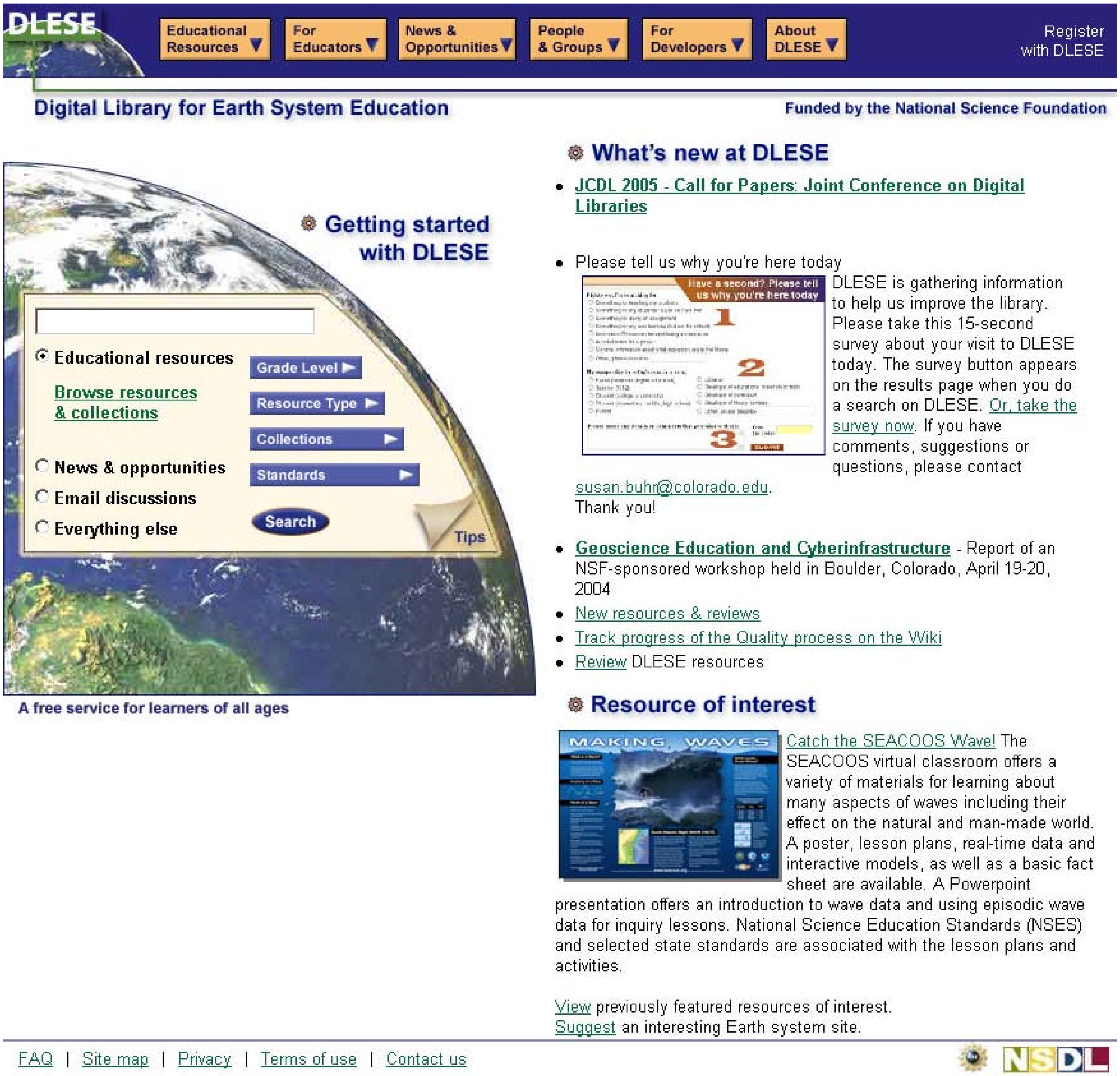
Figure Caption

Figure 3.1. Screen capture of DLESE homepage.


DLESE
Educational Resources
For Educators
News & Opportunities
People & Groups
For Developers
About DLESE
Register with DLESE
Digital Library for Earth System Education
Funded by the National Science Foundation
Getting started with DLESE
Educational resources
Browse resources & collections
Grade Level
Resource Type
Collections
Standards
News & opportunities
Email discussions
Everything else
Search
Tips
A free service for learners of all ages
What's new at DLESE
JCDL 2005 - Call for Papers: Joint Conference on Digital Libraries
Please tell us why you're here today
Have a second? Please tell us why you're here today
DLESE is gathering information to help us improve the library. Please take this 15-second survey about your visit to DLESE today. The survey button appears on the results page when you do a search on DLESE. Or, take the survey now. If you have comments, suggestions or questions, please contact susan.buhr@colorado.edu.
Thank you!
Geoscience Education and Cyberinfrastructure - Report of an NSF-sponsored workshop held in Boulder, Colorado, April 19-20, 2004
New resources & reviews
Track progress of the Quality process on the Wiki
Review DLESE resources
Resource of interest
MAKING WAVES
Catch the SEACOOS Wave! The SEACOOS virtual classroom offers a variety of materials for learning about many aspects of waves including their effect on the natural and man-made world. A poster, lesson plans, real-time data and interactive models, as well as a basic fact sheet are available. A Powerpoint presentation offers an introduction to wave data and using episodic wave data for inquiry lessons. National Science Education Standards (NSES) and selected state standards are associated with the lesson plans and activities.
View previously featured resources of interest.
Suggest an interesting Earth system site.
FAQ | Site map | Privacy | Terms of use | Contact us
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CHAPTER 4

STUDENT ENGAGEMENT IN INQUIRY-BASED LEARNING IN AN UNDERGRADUATE GEOLOGY COURSE[1]

[1] Apedoe, X. S. To be submitted to the *Journal of Research in Science Teaching*

Abstract

This paper reports the synthesis of three case studies of students' engagement in inquiry-based learning activities in an undergraduate geology course. Details of how students engaged in scientific questions, gave priority to evidence, formulated explanations, evaluated explanations, and communicated and justified their findings are presented. Data for this study included classroom observations and field-notes of classroom practices, questionnaires, archival data (e.g., student work samples) and audiotapes and transcripts of interviews conducted with the student participants throughout the course. The results suggest that although these students were able to successfully appropriate inquiry practices (e.g., giving priority to evidence), it was not without its challenges (e.g., perceived lack of guidance). A detailed discussion of the ways in which students were successful, and where they had challenges engaging in inquiry is presented, with the goal of helping direct practitioners and researchers to strategies whereby students' inquiry experiences can be improved.

Student Engagement in Inquiry-based Learning in an Undergraduate Geology Course

In recent years, there has been a revolution in geosciences education promoting a re-conceptualization of teaching and learning in both its goals and methods. *Blueprint for Change: A Report from The National Conference on the Revolution in Earth and Space Science Education* (Barstow & Geary, 2002) details this bold new vision for earth science education. This report describes the purpose of the revolution as being two-fold: (a) to change the *nature* of earth and space science education, and (b) to change the *extent* of student participation in earth and space science education.

Although *Blueprint for Change* focuses primarily in the geosciences in the K-12 sector, the report has important implications for how geology, geography, and other geosciences are taught and learned at the undergraduate level. This paper reports the findings of an investigation of student engagement in inquiry-based learning in an undergraduate geology course that utilized teaching and learning strategies supportive of the recommendations found in *Blueprint for Change.*

Learning in the Science Classroom

> "In many respects, the geosciences are the most visual of all disciplines.
> They also may be among the least amenable to the traditional lecture format
> of teaching."
>
> (National Science Foundation, 1996)

For far too many years, the emphasis and goal of science education has primarily been helping students acquire factual knowledge. Science instruction, at all educational levels, typically has been focused on covering content from the textbook, exposing students to a plethora of facts but rarely, if ever, engaging students in the process of science (National Research Council, 1996b). Yore, Florence, Pearson and Weaver (2002) have described this unfortunate trend as the 'science as a noun' perspective which "stress[es] encyclopedic volumes of knowledge and lists of procedures and processes about science" (p. 5). Despite periodic calls for reform, superficial coverage of scientific concepts and emphasis on the teaching of facts remains the dominant approach to instruction in science education (Bransford, Brown, & Cocking, 2000).

There are two serious consequences of not engaging students in the process of science in the classroom. First, research suggests that students develop false beliefs about the nature of science, believing that: (a) science re-describes an event or phenomenon, (b) an authority figure warrants what can be considered scientific knowledge, and (c) scientific knowledge is acquired through an empirical process (Qian & Alvermann, 2000). Second, students are prone to either develop or maintain strong misconceptions about science-related concepts. Research has shown that even following instruction that addresses common fallacies, students are prone to hold onto their misconceptions (Alexander, 1998).

Although it remains much more in the realm of theory rather than practice, within the science education community there has been a move towards adopting a 'science as a verb' perspective which "emphasiz[es] the human endeavors, successes, failures, and emotional dispositions associated with doing science as inquiry" (Yore, Florence, Pearson, & Weaver, 2002, p. 5). This is particularly the case in earth science:

> We first need to broaden the goals of instruction in Earth system science to go beyond coverage of a certain body of content. Earth system science instruction should not only incorporate genuine inquiry and hands on experience but also teach communication skills, teamwork, critical thinking, and lifelong learning skills
>
> (American Geophysical Union, 1996, Panel 3 Discussion, para 4)

Blueprint for Change advocates adopting the 'science as a verb' perspective in earth science education. Earth and space science educational experiences should help students develop thinking skills such as inquiry, visual literacy, understanding of systems and models and the ability to apply knowledge and problem solving to a range of substantive, real-world issues (Barstow & Geary, 2002). To accomplish such goals, *Blueprint for Change* recommends that learning experiences encompass and emphasize use of inquiry-based learning and visualization technologies, to promote understanding of Earth as a system. These recommendations are based on the *National Science Education Standards* (National Research Council, 1996a) and the *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993) (Barstow & Geary, 2002).

Inquiry-based Learning

There has been a renewed interest in the use of inquiry-based learning in science classrooms at all grade levels since the National Research Council (NRC) released the National Science Education Standards (NSES) nearly a decade ago (National Research Council, 1996a). The NSES reject the traditional emphasis on memorization and recitation of facts in science, rather they call for inquiry to play a significant role in science teaching and learning (Edelson, 2001). Inquiry describes the "diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" (National Research Council, 1996a, p.23). Inquiry also refers to the learning activities of students "in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (National Research Council, 1996a, p. 23). Thus inquiry describes both a process that scientists use to investigate phenomena in the natural world, as well as an instructional methodology that can help students achieve understanding of scientific concepts by participating in research activities typical of working scientists.

Inquiry as a teaching methodology and learning experience emphasizes providing students with opportunities to engage in activities very similar to those required for real world scientific research. When learners are engaged in inquiry-based learning environments they should (National Research Council, 2000):

- Be engaged in scientifically oriented questions
- Give priority to evidence, allowing them to develop and evaluate explanations that address scientifically oriented questions
- Formulate explanations from evidence to address scientifically oriented questions
- Evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding
- Communicate and justify their proposed explanations

These five elements are essential characteristics of an inquiry-based learning environment. Variations in the amount of learner self-direction and direction from the teacher or learning materials characterize a specific inquiry-based learning environment as more "guided" or "open" (National Research Council, 2000). Guided inquiry and open inquiry are used to support different learning goals. "[G]uided inquiry can best focus learning on the development of particular science concepts. More open inquiry will afford the best opportunities for cognitive development and scientific reasoning" (National Research Council, 2000, p. 30). All variations of inquiry are acceptable provided "the learning experience centers on scientifically oriented questions that engage students' thinking" (National Research Council, 2000, p. 28).

Although the NSES were aimed specifically at K-12 students and teachers, the recommendations contained in the reforms can and should be generalized to college science teaching (McIntosh, 2000). University and college instructors can play an integral role in leading science education reforms. University and college science instructors are responsible for fostering the development of students': (a) scientific knowledge (b) understanding of the nature of science, (c) ability to appropriate and understand scientific ways of thinking and (d) ability to make connections between their learning and the outside world (Siebert & McIntosh, 2001).

The importance of utilizing inquiry-based methods in university and college science classrooms cannot be overemphasized. As more and more students are exposed to inquiry-based learning approaches in their K-12 science education, the necessity for postsecondary science instructors to adapt their teaching approaches increases. Students will soon be entering college and university science courses with strong inquiry skills and raised expectations for being engaged in science, and their instructors must be ready to meet the challenge. But in order to effectively design instructional activities to promote inquiry learning, more research that focuses on student experiences in an inquiry environment is needed.

Research on Inquiry: Past and Present

Since the 1960s, inquiry-based teaching approaches have been advocated among science educators to help promote students' critical thinking, conceptual understanding and scientific reasoning abilities (Cavallo, Potter, & Rozman, 2004). Studies of the inquiry-based curricula and programs from the 1960s and beyond have been very supportive of inquiry approaches for supporting student learning (Haury, 1993). Inquiry-based learning allows students to engage with the material, build on their prior knowledge, and improve their grasp of the scientific method and its strengths and weaknesses (Keller, Allen-King, & O'Brien, 2000). Engaging in inquiry also provides students with experience in processes that characterize authentic scientific practice such as questioning, evidence gathering and analysis (Edelson, 2001).

The majority of research and development on inquiry-based programs and curricula have been at the elementary and secondary school levels (Cavallo, Potter, & Rozman, 2004). Studies on these curricula and projects have found that students in inquiry-based classrooms formulate sound understandings of science processes and content (Cavallo, Potter, & Rozman, 2004), demonstrate improved scientific reasoning abilities (Gerber, Cavallo, & Marek, 2001), and among other competencies, improved scientific literacy and critical thinking (Haury, 1993). Other studies on the use of inquiry-based learning approaches point to a number of other positive outcomes such as an increase in vocabulary knowledge, conceptual understanding, critical thinking, inquiry abilities, and positive attitudes toward science (National Research Council, 2000).

To date, research on inquiry-based learning has focused on demonstrating the benefits of inquiry for the development of students' cognitive abilities such as critical thinking, scientific reasoning, and understanding of scientific concepts. However, with the current emphasis on learning not only scientific knowledge, but also the processes and procedures that produced such knowledge (inquiry), educational researchers have become increasingly interested in students' understanding and ability to appropriate scientific inquiry practices (Kanari & Millar, 2004). It is important that we know what is being done, and how it is being done, when students are engaged in inquiry activities (Wheeler, 2000), so that we can develop guidelines for successfully incorporating inquiry activities into classrooms at all educational levels. Although there is currently little research examining how students are engaging in inquiry and appropriating specific inquiry practices, research studies like those conducted by Krajcik et al. (1998), Hofstein, Shore, and Kipnis (2004), and Kanari and Millar (2004) are examples of what is needed.

Krajcik et al. (1998) reports the results of a study that investigated middle school students' initial attempts at inquiry-based learning. The focus of this study was on how students engaged in the inquiry processes of asking questions, designing investigations, collecting data, formulating explanations, and communicating and justifying explanations. Results from their study suggest that middle school students can successfully engage in inquiry processes, and with appropriate support and scaffolding can demonstrate growth in their abilities to engage in inquiry. Students were proficient in designing and planning investigations (e.g., considering issues of experimental controls), however they had difficulties with processes such as systematically collecting and analyzing data, and drawing appropriate conclusions from their data. Krajcik et al.'s study has contributed to the literature a realistic picture of how middle school students engage in inquiry, and the challenges that they face.

Hofstein, Shore and Kipnis (2004) developed, implemented and assessed student learning in a high school inquiry-based chemistry laboratory course. Similar to the aspects of inquiry which were the focus of Krajcik et al.'s. (1998) study, Hofstein et al. (2004) focused on the inquiry processes of (a) asking relevant questions, (b) formulating hypotheses in line with those questions, (c) choosing researchable questions for further investigation, and (d) planning experiments to investigate those research questions. Hofstein et al. found that high school students showed significant changes in the types of questions they asked as a result of their involvement in inquiry activities. Inexperienced students tended to ask low-level qualitative type questions related to their recent experiences in the classroom or laboratory, but as students gained more experience with inquiry, they asked more quantitative questions, and more questions related to inquiry in the chemistry laboratory. In addition, after more inquiry experience, students were able to ask more sophisticated questions, and to plan experiments that were highly related to the research question. Based on the positive findings, these researchers concluded that students' inquiry abilities can be improved with time and experience.

Finally, Kanari and Millar (2004) investigated the ability of students aged 10 –14 years old, to reason from data collected as part of a practical inquiry task. Rather than focus on multiple inquiry processes as Krajcik et al., (1998) and Hofstein et al. (2004) did, Kanari and Millar (2004) chose to focus on the inquiry processes of collecting and reasoning from data. One goal of their study was to identify common approaches or patterns that students used when reasoning from data. Results from their study suggest that students have difficulty reasoning from data in situations where error matters. However, results also suggest that students as young as age 10 can develop competence in carrying out investigations examining the relationship between variables that covary.

While these three noteworthy studies provide much needed insight into how students are engaged in inquiry, and what students are doing while engaged in inquiry activities, research is still needed to illuminate the experiences of students pursuing inquiry in higher education. The value of such research is that it can be used to help inform educators of appropriate instructional practices to promote effective learning through inquiry (Krajcik et al., 1998). By examining students' engagement in inquiry at all levels of education, educational researchers will be able to begin to develop guidelines and recommendations for ways to effectively utilize support from teachers, peers or technology, to enhance student participation in inquiry processes.

This paper reports the synthesis of three case studies of students' engagement in inquiry-based learning activities in an undergraduate geology laboratory. Details of how students engaged in scientific questions, gave priority to evidence, formulated explanations, evaluated explanations, and communicated and justified their findings are presented. A goal of this research has been to describe realistically what college students do, and where they experience challenges, when engaged in inquiry activities.

The Study

The data for this paper was derived from a semester-long investigation of the use of inquiry-based learning activities supported by access to, and use of, resources in a digital library. Of primary interest here was how students appropriated and engaged in scientific inquiry practices. The following research questions were addressed:

1. How do students appropriate and engage in inquiry processes in an inquiry-based undergraduate geology laboratory?
2. What challenges do students experience with engaging in inquiry processes in an inquiry-based undergraduate geology laboratory?

Context and Setting

This research was conducted in a geology course entitled Life and Ecologies of the Past, taught at a large research university located in the southeastern USA. See Appendix G for a copy of the syllabus. The course was an upper-level undergraduate geology course consisting of 2 hours of lecture and 3 hours of lab per week. The researcher worked collaboratively with the course instructor to re-design the activities used in the laboratory component of the course. The instructor was the primary designer of the lab activities, while the researcher served in a consulting role, providing feedback and suggestions for creating activities consistent with inquiry-based learning goals.

The impetus of this laboratory course redesign was two-fold. First, the instructor of the course expressed a concern about previous students' performance on her inquiry-based exams. The instructor, who was familiar with inquiry-based approaches for teaching and learning, had been utilizing inquiry-type exams, but had not frequently engaged her students in inquiry-based activities prior to the exams. Thus, students typically performed poorly on the exams, likely because they had very little prior experience with inquiry-based activities and had a difficult time ascertaining what was expected of them.

Second, the researcher was interested in investigating how a digital library developed specifically for the earth sciences could be used by instructors and students to support teaching and learning in an inquiry-based geoscience course. Thus, it was decided that the Digital Library for Earth Systems Education (DLESE) would be incorporated into the re-designed laboratory component of the course.

Course Description

Course Objectives. The learning goals associated with this laboratory course redesign were to: (a) develop skills necessary to participate in scientific inquiry processes related to geological inquiry, and (b) develop deep understanding of the relevant geology content, (e.g., to help students learn the applied aspect of paleoenvironmental analysis and relative age-dating by using fossil organisms).

Content. The course that served as the context for this study focused on principles of paleobiology, including biostratigraphy, paleoecology, taphonomy, and macroevolutionary dynamics. Content for the course and laboratory was presented in a manner consistent with inquiry-based pedagogical approaches, that is, students were given the opportunity to interact with numerous rock and fossil samples in the process of conducting scientific investigations. In addition, students were encouraged to access dynamic and static resources in a digital library specifically developed for the geosciences, the Digital Library for Earth Systems Education (DLESE – available at: http://www.dlese.org). Students also had access to more highly structured information, such as that found in their textbook or instructor provided *Paleonotes* (an instructor developed 'cheat sheet' on many of the topics dealt with in course). Other resources used included locality maps, and pictures that often accompanied the samples presented in the lab.

Tasks. The inquiry tasks were structured according to guidelines for creating inquiry-based learning environments suggested in the NSES. Variations in the amount of learner self-direction and direction from the teacher and/or learning materials, characterize each inquiry-based learning task as more "guided" or "open" (National Research Council, 2000). The inquiry-tasks used in this course were more "guided' than "open" inquiry tasks, in that students were provided with an inquiry question to pursue and provided with a multitude of data from which to formulate their explanations. However, unlike traditional 'cookbook' laboratory activities in which all the important decisions such as which data should be collected, how data should be analyzed, what the data means, etc. (Clough, 2002), these inquiry tasks were designed to encourage students to actively engage in cognitive activities that are integral to engaging in inquiry. Activities integral to inquiry and to the inquiry tasks used in this laboratory, such as developing alternative explanations, interpreting data, selecting among alternative hypotheses, etc., are examples of activities that mentally engage students (Clough, 2002). See Appendix H for a characterization of each inquiry task based on the NSES guidelines. See Appendix I for copies of the inquiry tasks that were analyzed as part of this study.

Instructors' roles. The instructor for this course was very familiar with inquiry-based teaching practices, and thus felt very comfortable acting as a facilitator for students learning through inquiry. However, the teaching assistant for the course had very little prior experience in facilitating student learning in an inquiry-environment, and thus was less comfortable and skilled in the process. The impact of the facilitation skills of the instructors is discussed in more detail later in the paper.

Students' roles. Students were required to be active participants to complete the inquiry tasks in this laboratory, working both collaboratively and independently. Students were given the option of working individually or in groups to complete inquiry assignments. An example of directions from Lab Exercise 2 is provided below:

> *[Excerpt from Lab Exercise 2 Instructions]*
> *I. <u>Work Station No. 1.</u> <u>First</u>, discuss in your groups (or individually!) the biological criteria for life that you are most familiar with from your background and make a list of these criteria.*

Technological affordances: Students had access to a specific digital library designed to support teaching and learning in the geosciences (DLESE – http://www.dlese.org). Access to DLESE was provided in the classroom, and students were encouraged to use it while completing their inquiry assignments, but use was not required. The DLESE library currently houses over 9,000 resources, about 45% of which are in the 19 thematic collections related to a range of topics dealing with earth science. Its features include the ability to search for resources according to: educational level (including the first two years of undergraduate geosciences, the last two years of undergraduate school, and graduate level resources); resource type (e.g., lesson plans, visualization data, animations, and video); collections (DLESE resources that are organized by themes or other evaluative criteria, e.g., DLESE Reviewed Collection); and standards (including the National Science Education Standards and the National Geography Standards). Once a resource of interest is found, a summary of the resource's properties is displayed including: a brief description of the resource; resource type; subject areas addressed; and the educational level for which the resource is appropriate. Users are also able to see reviews of the resource provided by other teachers and students, teaching tips for using the resource in a class, and other resources related to the topic of interest.

Assessment strategies. In line with inquiry-based pedagogical approaches, multiple assessment strategies were used in this course, including lab reports and inquiry-based exams. See Appendix C for copies of the midterm and final exam. Final grades in the course were based upon: two in-lab quizzes; one inquiry-based midterm in-lab exam; one inquiry-based final take-home exam; one field trip research paper and presentation; one individual project; one in-lab debate; and eight lab reports.

Method

Research Design

This study utilized a layered case-study approach that included both an analysis of one macro-level case and cross-case analyses of several individuals (Patton, 2002). The unit of analysis for the investigation reported in this paper was the individual student. The results of the macro-level case analysis are reported elsewhere.

Participant Selection

All students were invited to participate in this research on a voluntary basis. A total of 8 students were enrolled in the course, of which 7 students agreed to participate in the study. Purposeful sampling (Patton, 2002) was used to select three individuals who could serve as information-rich cases to be studied in-depth. From the various types of purposeful sampling (e.g., extreme case, intensity, maximum variation, homogenous, critical case, etc.), typical case sampling was used to describe and illustrate three students that are similar to the type of student that would be expected to enroll in this geology course in the future. Typical cases can be selected using survey data, demographics, or information from key informants knowledgeable about the environment (Patton, 2002). For this study, information from the instructor (key informant) as well as questionnaire responses and demographic information were used to select three participants at the beginning of the semester. Participants have all been given pseudonym names.

Based on questionnaire, demographics and information from the instructor, Jackson, Jake, and Karen were identified as exemplifying typical students for this geology course. Jackson, Jake and Karen were geology majors who were each the age (20-22) of students who commonly enrolled in this course. These three students provided rich information and details in their surveys and interviews. The other students were not chosen to serve as cases for this study for a variety of reasons. For example, Drake was enrolled in the course for the second time, thus he was deemed not to be a good example of a typical student. Kyle was a non-traditional student who had returned to university for training in a second career. Melanie was not chosen because she was an anthropology major, rather than a geology major. Finally, Robin, although in many respects exemplified a typical student, was not chosen to serve as a case in this study because she did not provide as much detail or information in her interviews or questionnaires as the three chosen students. See Table 4.1 for a detailed characterization of the three students chosen to serve as cases for this study.

Based on interview responses, questionnaire responses, and classroom observations, Jackson, Jake and Karen, who were selected to serve as cases for this study, were characterized in the following ways:

- *Jackson*, a 20 year old, 3rd year student, was friendly and laid-back. He was a geology major and forestry minor. Jackson's decision to become a geology major stemmed from his experience in high school. Jackson stated: "*Well I had taken some classes in*

Table 4.1: Characterization of Students Selected as Cases in the Geology Course

Characteristics/ Participants	Age/Gender	Standing	Major/ Minor	Geology Background	Comfort with Inquiry?	Comfort with computers/ WWW?
Jackson	20 year old/ Male	3rd year student	Geology/ Forestry	7 credit hours	Comfortable	Not very comfortable
Jake	22 year old/ Male	5th year student	Geology	7 credit hours	Comfortable	Very comfortable
Karen	20 year old/ Female	3rd year student	Geology	12 credit hours	Comfortable	Very comfortable

high school and we had a really great teacher and he kind of turned me on to it and I hadn't really ever looked back since. I mean it's the only thing I've ever really been interested in that much as far as classes go." Although Jackson was a fairly outgoing person, he was not very vocal in class, rarely asking questions or making comments. Jackson indicated that he was familiar with inquiry-based learning, and that he believed he would be comfortable with this type of learning approach. Jackson was also very comfortable collaborating with others to complete group projects. When asked about his comfort level using computers or the World Wide Web (WWW), Jackson indicated that he was not at all comfortable, stating: *"…I'm not a real big computer person – I try to use computers as little as possible to tell you the truth."* Finally, on a pre-course survey Jackson indicated that his level of motivation for learning in the course was high.

- *Jake*, a 22-year old, 5th year student was a well-liked outgoing student, who immediately took a leadership role when working with group members to complete inquiry assignments. Jake, became a geology major after transferring from the Business program at another university. On a pre-course survey, Jake indicated that he was not familiar with inquiry-based learning, but believed that he would be very comfortable with this learning approach. Jake also rated his comfort level for learning through group projects as very comfortable. With regards to his comfort level using computers and the WWW, Jake rated himself as being very comfortable with their use. Finally, Jake described himself as a very motivated student in general, and especially motivated for learning in this particular geology course, stating: "*Cause I'll tell you right now, I love geology. I want to be in here and I want to learn as much as possible. I go to class everyday trying to, you know, get better."*

- *Karen*, a 20 year old, 3rd year student was the quietest of the 3 students. She often worked closely with Jake to complete inquiry tasks. She chose geology as her major after having a great experience in an introductory course she took during her second year at the university. Karen had the most experience in geology, having participated in a research internship experience the previous summer, and attending and presenting at the Geological Society Association Annual meeting during the Fall of 2004. Based on data from a pre-course survey and follow-up interviews, Karen was familiar with inquiry-based learning and believed that she would be comfortable with this learning approach. However, Karen was not comfortable learning through group projects stating: *"…I feel like I usually get stuck with people that have like really strong opinions, and its hard for me to get my ideas in there and be confident enough to like push ideas that I know are really good or that I really like and I think it's a good idea…"* Karen preferred assignments in which each student was responsible for and earned their own grades. With respect to comfort levels with computers and the WWW, Karen indicated that she was very comfortable with both. Finally, Karen described her motivation for learning in the course as high, stating: "*This is not my favorite material, but I want to know it.*"

Data Collection

The collection of information for the type of case analysis conducted for this study typically come from interviews, observations, documents, impressions and statements from others, and contextual information (Patton, 2002). In this study, multiple data collection procedures such as observation, document analysis, and interviews were used to help address the research questions of interest.

Student participation primarily involved completion of three questionnaires and three interviews throughout the semester (beginning, middle and end of semester). In addition to the questionnaires and interviews, student participants allowed the researcher to access copies of their completed assignments and exams, and agreed to be observed as they completed inquiry-assignments during lab time. See Table 4.2 for a detailed description of the research questions, and their associated sources of data.

During the implementation phase of the research, both process measures and outcome measures were collected. Process measures consisted of observations of student behaviors and discussions. Outcome measures included students' performance on mid-term and final examinations, and final products of inquiry assignments. These measures are explained in further detail below.

In-depth qualitative interviews in which participants were asked to respond to a series of open-ended questions that included questions related to their understanding of geology content, inquiry processes, and their participation in inquiry activities were used. See Appendix E for a sample of the interview protocols used. Interviews also contained questions that utilized a projection technique. The basis of the projection technique is to have individuals react to something, be it a photograph, film, story, or piece of work they have produced (Patton, 2002). Using the projection technique, participants in this study

Table 4.2. Summary of Data Sources

Research Questions	Method	Type of Data	Analysis Method	Frequency of Data Collected
1. How do students appropriate and engage in inquiry processes in an inquiry-based undergraduate geology course?	Archival Data	Lab Assignments/ Exams	Thematic & deductive analysis	8 Assignments 2 exams
	Interviews	Audiotapes and transcripts	Thematic, constant comparison. & deductive analysis	3
	Direct Observation	Field notes		12
2. What challenges do students experience with engaging in inquiry processes in an undergraduate inquiry-based geology course?	Interviews:	Audiotapes and transcripts	Thematic, constant comparison, & deductive analysis	3
	Direct Observation:	Field notes		12
	Questionnaires	Completed questionnaires		3

were given their completed inquiry assignments and asked questions about their engagement in inquiry processes based on their completed inquiry assignments. These interviews lasted approximately 30-45 minutes and occurred 3 times during the semester (at the beginning, middle and end of semester).

Participant observation was used throughout the semester. During every lab period (3 hours per week), the researcher observed student participants working to complete their inquiry assignments. For this study, particular attention was given to students' activities and behaviors as they completed their inquiry assignments, to provide insight into how students' participation in inquiry processes evolved throughout the semester. The researcher recorded field notes, which were expanded and analyzed following the lab period in which they were collected.

Archival Data such as completed inquiry assignments, mid-term and final exams, were used as outcome measures. Performance on inquiry assignments, mid-term, and final exams were analyzed in conjunction with observation and interview data to provide a deeper understanding of how students engaged in inquiry processes.

Data Analysis

Data was analyzed in two phases. In the first phase, interview transcripts, questionnaire data, classroom observation field-notes, and students' archival data were analyzed in multiple passes by the researcher (Miles & Huberman, 1994). In the second phase of data analysis, cases were created for each of the three students using a combination of observation field-notes, interviews, questionnaire, and archival data (inquiry assignment reports).

Data analysis: Phase one.

A detailed description of the analysis procedures used on each pass with the various data sources (e.g. interview transcripts, observation field-notes, etc) during the first phase of data analysis is described below.

Interview transcripts. On one pass, a thematic analysis procedure was used to analyze the interview transcripts. Thematic analysis is an inductive analysis procedure in which categories are derived from the data, that is, the specific nature of the themes and categories are not predetermined (Ezzy, 2002). Thus, the interview transcripts were explored, units of meaning were identified, codes were developed and categories and sub-categories were created (Ezzy, 2002). This process was followed until a 'master list' of codes was developed, which reflected the recurring themes and patterns in interviewees' responses (Merriam, 1998).

On a second pass, the constant comparative method of analysis (Merriam, 1998) was used to code interview transcripts with respect to the interview questions. This process involved examining interview transcripts, comparing codes identified on the 'master list' of codes, and then organizing the coded data according to each interview question that it addressed. Individuals' responses to interview questions were compared across interviews to identify any themes or categories that may have been missed in during the initial coding pass. Then the coded responses were compared across interviews to identify any new themes or categories that were specific to the interview question being addressed.

On a third pass, the constant comparative method of analysis was employed again, however this time it was used to examine interview transcripts in light of the two major research questions. The coded interview data was organized according to the research question that it specifically addressed followed by the comparison of individuals' coded responses across interviews.

Finally, on a fourth pass, a deductive analysis (Patton, 2002) approach was used, in which the interview responses were categorized according to the five essential characteristics of an inquiry-based learning environment, as described in the NSES. In addition, several additional specific questions that related to each component of the inquiry process were used to guide analysis of the interview transcripts and to categorize the coded interview responses. These questions were developed based on research conducted by Krajick et al. (1998). Table 4.3 presents the five essential components of inquiry and the associated questions used for data analysis. These four coding passes allowed the researcher to conduct detailed, cross-coded searches for themes and categories in the interview data.

Questionnaire, Field-note & Archival Data. A similar analysis procedure was used for coding of the open-ended questions from the questionnaires, the field-notes from the direct classroom observations, and the students' archival data (inquiry assignment lab reports). Of the eight inquiry assignments that students completed, four inquiry assignments were chosen for analysis. These assignments were chosen because they represented assignments that had undergone the most significant revision in the course re-design. On the first pass of the data, a thematic analysis procedure was used to identify any categories or themes that emerged from participants' responses, behaviors, or work samples. On the second pass, constant comparative analysis was used to code the questionnaire, lab report, and field-note data against the research questions. Questionnaire data underwent a third pass of coding, based on the questions to which the participants responded. Finally, deductive analysis, based on the inquiry components and analysis questions identified in Table 4.3, was used to organize the coded questionnaire, field-note, and archival data. In combination with the interview, questionnaire, and archival data, the field notes from direct classroom observations were used as a source to validate and crosscheck findings (Patton, 2002).

Data analysis: Phase two

In the second phase of data analysis, cases were created for each of the three students using a combination of observation field-notes, interviews, questionnaire, and archival data (inquiry assignment reports). The resultant student cases consisted of a summary of how each student engaged in each aspect of inquiry (e.g., engaging in scientific questions, formulating explanations, etc.). See Appendix J for the case reports of the three students.

Results

The results are presented in two sections according to research questions. In the first section, each component of inquiry is presented based on the NSES of inquiry processes to engage in followed by a description of how each student engaged in that inquiry process. In the second section, challenges each student experienced with inquiry-based learning are presented.

Table 4.3: Inquiry Components, Analysis Questions, and Data Sources

Inquiry Process	Analysis questions	Data Sources
Engage in scientifically oriented questions	Did students raise other science-related questions?	Observation field-notes Archival Data (lab reports)
Give priority to evidence	In what ways did students plan to organize and track data collection? Were students thorough, systematic, and precise in collecting and describing data? Did students create different representations of data through charts, graphs, or summary tables?	Observation field-notes Interviews Archival Data (lab reports)
Formulate explanations from evidence	What data did students use to formulate explanations and how did they use it? Were students accurate in interpreting the data?	Archival data (lab reports)
Evaluate explanations in light of alternatives	Did students gather and draw on background information, consider alternatives, and make predictions? What resources did students use?	Observation field-notes Interviews
Communicate and justify proposed explanations	How did students present their conclusions? Did they use the data to justify their conclusions?	Archival data (lab reports) Observations (class presentations)

Research Question 1: *How do students appropriate and engage in inquiry processes in an inquiry-based undergraduate geology course?*

Engaging in scientific questioning.

For this inquiry skill, data was analyzed in relation to the question 'Did students raise other science-related questions?' Because all inquiry assignments required students to engage in answering the same overall questions, it was of interest to the researcher whether students would build on their investigations to begin to ask other science-related questions.

Jackson

Jackson did not often raise other questions while engaged in inquiry. From classroom observations, he seemed predominantly focused on addressing the inquiry question provided in the assignment. However, when Jackson did raise questions, the purpose of the question could be characterized in one of three ways: (a) to clarify his knowledge or understanding of a topic, (b) to clarify his observations, or (c) to make a prediction.

An example of a clarification of knowledge question, is demonstrated in the following interaction between Jackson and the teaching assistant (TA):

> *[Discussing the possible composition and depositional environment of a rock sample]*
> *TA: This way it definitely looks clast-supported. Go with whatever is most common looking in the rock. You can say in some locations it is clast-supported while in others it is matrix-supported*
> *Jackson: And it would be from a big flash flood rather than a meandering stream or something…*
> *TA: It could be a meandering stream*
> *Jackson: Wouldn't a meandering stream make a more uniform rock?*

Jackson's last question about what type of rock a meandering stream creates, demonstrates that he is pulling from his prior knowledge about what types of depositional environments form what types of rocks. In this interaction with the TA, Jackson is seeking clarification about his prior knowledge.

A clarification of observation question is one in which the student asks a direct question about samples they were observing to check their accuracy in identifying and interpreting the data. An example of a question Jackson asked to clarify his observations includes: *"I thought this exhibited graded bedding? What did you put?"* Jackson, used clarification of observation questions with his peers, the TA, and the instructor, to check his understanding of what he was observing in the data.

Finally, Jackson also used questions as prediction statements when engaged in discussions with his peers. An example of a prediction question would include, "*Couldn't it be micritic mud?"* These questions were used most frequently during the data collection phase and usually used as a way to pose an alternative hypothesis to what was currently being discussed by the group.

Jackson was observed only once asking a question to fulfill his curiosity about a topic. In the following interaction with Dr. Sanders (the instructor), Jackson asked for more detail about a sample obsidian rock:

Jackson to Dr. Sanders: Obsidian [asks her something about how it is made or at what temperature it is made at?]
Dr. Sanders: I don't know exactly how to answer that question. Dr. Green would be able to answer what the exact temperature would be.
Jackson: I was just wondering if there was a specific process that made it.
Dr. Sanders: Yeah, I'm not sure, but that's a really good question.

Jake

Of all the students, Jake engaged in the most questioning with other students, the TA and Dr. Sanders. While completing the inquiry tasks analyzed as part of this case study, Jake was observed asking a total of 17 questions, almost two-times as many questions as Jackson (9 total), and a little more than 4-times as many questions as Karen (4 total). Jake displayed a keen interest in learning the course material, and thus was consistently engaged in asking questions to build on his previous understanding of concepts. Rather than just clarifying what he already knew, Jake's questions often demonstrated his desire to understand the reasoning or rationale behind a particular idea or explanation. For example, during one lab exercise while working on determining whether a sample showed signs of biogenicity, Jake remarked:

Jake: What process would possibly cause that to be abiotic?
Dr. Sanders: Excellent question! That's exactly what you should be asking. Do you know these are super famous rocks?
Jake: We don't know what we're looking for to determine if it is biogenic or not…

Jake, like Jackson, also asked questions to clarify his previous knowledge. In the following observed interaction with the TA, Jake asked a clarification of knowledge question, followed by a building of knowledge question:

Jake: If it was from a water deposit wouldn't the beds not be so refined?
TA: Not necessarily. I have some rocks that look like that, that I found in water.
Jake: What kinds of water would do that? I guess what we need to know is exactly what would indicate what exactly to look for to prove it, to know what would indicate like a dune or something. We're looking at this rock and trying to accumulate evidence to show that this is a dune, so you were talking about grain size, so to me that's like another check box…

In addition to asking questions to build his knowledge and clarify his previous knowledge, Jake also used questions to clarify his observations (e.g., *"Is there gradation in this rock?"*) and as prediction statements (e.g., *"Maybe its veins are some sort of igneous material?"*).

Karen

Karen was the least vocal of the three students, and thus was rarely observed asking questions of her peers, the instructor, or TA. However, in the few instances in which Karen was observed asking questions they could be characterized as being clarification of knowledge questions. The following is a brief example of an interaction between Karen, Jackson and another student, Melanie, in which Karen asks a clarification of knowledge question:

Karen: Another thing to consider are the rings. Stromatolites do grow in layers right?
Melanie: Does this fit our criteria?
Jackson: How can we tell by looking at the rock though?

In summary, all students did ask other science related questions, all to varying extents. The types of questions students tended to ask included (a) clarification of knowledge, (b) clarification of observations, (c) prediction, and (d) knowledge building. However, Jake was the only student who engaged in asking knowledge-building questions. These are the types of questions that scientists ask and ideally that students engaged in inquiry-based learning will also ask.

Giving priority to evidence.

For this inquiry skill, analysis of the data focused on three questions: (1) In what ways did students plan and track data collection?, (2) Were they systematic and precise in collecting and describing data?, and (3) Did students create different representations of data through charts, graphs or summary tables?

For each inquiry assignment students were typically presented with a large set of samples (rock, fossils, slides, petrographs) that they were to examine in order to address the inquiry questions. It was not necessary for students to examine each sample, rather they were required to develop a plan for deciding which data it was necessary to collect.

Unfortunately, there was very little evidence to fully address the first question, especially related to student *planning* of their data collection. Indeed, it seemed that Jackson, Jake and Karen quickly developed a sense of what types of data they should be collecting and how to go about doing so. Jackson, Jake and Karen spent a great deal of time during the lab period collecting data and they almost always began collecting data immediately without much hesitation. Thus, planning (or lack thereof) their data collection methods did not seem to be an issue for these particular students.

With regards to the second question, 'Were students systematic in collecting and describing their data?' more evidence was available. Based on classroom observations, interviews and students inquiry reports, Jackson, Jake and Karen would typically move station-to-station (or sample to sample) taking notes or drawing sketches as necessary, and thus were fairly systematic about their data collection. Although each student was required to produce an individual lab report, they often worked with a partner or in a group to collect their data. For example, Karen and Jake often would begin their data collection by starting at the same sample and proceeding through the lab station-by-station (or sample-by-sample) together. Some lab stations did not require collaborative work (e.g., a station where students were required to sketch a representative sample of a mollusk) and thus although students may have been working side-by-side, they were in essence working individually.

For most inquiry assignments, it would have been easiest for students to organize their data by creating a chart or data table, however students were not required to create some sort of alternative representation for their data. Students were free to collect and organize their data in any way that made sense to them. As described below, Jackson, Jake and Karen made use of data tables and charts when most appropriate.

Jackson

From observation and interview data it was clear that for Jackson, time spent in the lab was primarily for collecting data while reasoning and justifying explanations was to be done outside of lab. During the lab period, Jackson tended to primarily work with one partner, Melanie, however both Melanie and Jackson would often work collaboratively with Jake and Karen to collect data and formulate explanations. For example, often Melanie and Jackson would reach a station where Jake and Karen were discussing their observations (or vice-versa). Thus, Melanie and Jackson would typically join the discussion, helping Jake and Karen to formulate possible explanations for the data at that particular station.

Jackson appeared to have no difficulty with systematically collecting and describing his data, as he had already had limited experience in a previous class doing such procedures. However, Jackson talked about the difficulty of getting back into the routine of engaging in this inquiry process after a long period away from it:

> *…I mean you come back and you look at 30 different rocks, and I was used to doing that all last year and then with about 4 months off, just getting back in the swing of identifying rocks and stuff is probably the hardest part…*

Jackson was also a student who sometimes used alternative means to organize his data, creating data summary tables that he would attach to his final lab report. Creating data tables did not seem to be an unfamiliar process for Jackson, as was evident at the end of the first lab period when Jackson, while working with Karen, Jake, and Melanie, came up with a draft data table which he shared with the group as a way to organize all the data they had collected that period. Jackson also demonstrated on a number of inquiry reports that he was able to transform his collected data into meaningful alternative representations. Thus, it appears that Jackson had no difficulty with any of the various aspects of this inquiry component.

Jake

Jake expressed sentiments similar to Jackson's regarding his approach to data collection. His method of work was a bit different from the other students however, in that he was often playing 'catch-up' with regards to assignment completion:

> *Well…my method of operation when it comes to labs in Dr. Sanders class, you know - half of those labs I'm doing and I also have to do the lab from the week before that's due at 5 which I haven't finished. For those I'm in the lab trying to get the data and that's it. I do everything else at home, all the writing, all the conclusions, everything – I'm just trying to look at the samples and get what I need from the sample from that class room so that I mean, I can do everything else at home if I can have everything there.*

Jake, was an avid user of data charts, stating: "*Once again a data chart- I love data charts if I can find a way to use them…"* Jake believed that data charts were an easy way to organize his information. And he generalized this practice from his inquiry assignments to utilizing it on his midterm and final exams as well.

Karen.

Karen also appeared to experience little or no difficulty with this inquiry component. Karen, much like Jackson and Jake, spent the majority of her time in lab just collecting data, preferring to do the rest of the work necessary to complete the inquiry assignment at a later time. Karen described her procedure for collecting data during the 2nd inquiry assignment:

> *… And then we had stations, and we just went around to stations and drew pictures, and try to describe them. I like it in lab when we don't have to collect like too much data, and we can go home and kind of work on it…*

Karen was also an avid user of data charts, stating that they were helpful for developing a deeper understanding of the material:

> *…And…30 samples we did? No way! Oh yeah, it took me so long. I remember, at the [coffee] shop I made this chart so many times. And I had like an original, then I had like this one which is all organized, that helped me just organizing everything and um, also by phylum. And then I think I organized them maybe by time… And just making this chart, I felt good about this chart. I felt like I put time into it and had a chance to look at this stuff and organize it and that took a lot of time.*

Karen frequently attached data summary tables to her inquiry reports, demonstrating her competency in the *giving priority to evidence* aspect of inquiry.

Thus for these students, the lab period was viewed primarily as a time in which to gather all the necessary data to complete their inquiry assignments. The planning for, or collection of data did not seem to pose any challenge or difficulty for them, as they all had at least limited experience in previous classes in understanding how and what types of data to collect. In addition, creating different representations of their data seemed to help these three students to develop an understanding of the concepts and issues they were dealing with, supporting their ability to answer the inquiry questions of interest.

Formulate explanations from evidence.

Analysis of student engagement in this inquiry skill focused on two questions: (1) What data did students use to formulate explanations and how did they use it?, and (2) Were students accurate in interpreting the data? Since students were presented with numerous samples and types of data, completion of the inquiry assignments required them to not only determine what data to use, but also how to use the data to formulate their explanations.

Jackson.

Although in class Jackson was an active participant with his group in formulating solutions, he failed to translate this to his written lab report. Thus, he would often lose points on his inquiry report for omitting such details. For example, on his first lab report Jackson states: *"After examining the given rock samples, it is evident that the rocks in question tell us much about the formation of southwestern North America…"* Although this may be considered a good introductory sentence, Jackson does not provide further details regarding how the rocks were examined, or what types of data was obtained from the rock samples to warrant making such a claim.

During an interview, Jackson talked about his propensity to leave out supporting details from his lab reports:

> *…It seems like I don't go into as much detail as I should sometimes. I just don't even really think about it. I'll explain something but it seems like I won't go into explaining how we learned why those processes happen – that's probably been my biggest downfall…*

Thus this was an inquiry skill that Jackson was aware of needing to develop further in order to be successful in the class.

Despite Jackson's propensity to neglect to supply detail, he was often accurate in his interpretation of the data. He was very accurate in identifying samples (e.g., rock type, depositional environment, etc.), which he demonstrated in his written inquiry reports. Jackson received scores of 44%, 95%, 55%, and 85% on his inquiry reports. The low grades Jackson received on two of his inquiry reports were due to errors such as not answering a specific question or omitting specific details.

Jake.

Jake was very successful in expressing how he made use of his data to formulate his explanations in his lab reports. Jake's lab reports often provided a detailed description of the type of data collected, how it was collected, and how it was used to formulate explanations. The following is a brief excerpt from Jake's 1st lab report:

> *To collect data on these rocks, I enlisted the help of my esteemed colleagues Jackson, Melanie and Karen. We worked as a committee, going from one sample to the next trying to determine a set of facts about each rock. The first thing we would examine was the rocks locality, in order to obtain the context of this rock's formation within the suite of 30. Then we would try and determine what type of rock we were looking at, a process which has a method to it as well. For this, we would determine whether the rock was sedimentary, igneous, or metamorphic, as the processes associated with the creation of each is very telling about the environment they were created in…*

In this excerpt, Jake describes the process he and his peers went through to collect data. In addition, Jake describes the type of data collected (e.g., rock locality, type of rock) and how it can be used to formulate explanations.

Jake also consistently demonstrated a high degree of accuracy interpreting his data. Jake received grades of 92%, 85%, 93%, and 85% on his lab reports, demonstrating a high degree of competency with important course concepts.

Karen.

Karen, like Jake, was very successful in using data to formulate explanations. Karen describes what can be characterized as the typical process used by the students in terms of the type of data they collected to formulate their explanations:

> *For this one we had the ridiculous amount of samples. And for just the lab I uh, just took every rock and described as much as I could about it. I looked on the map and saw um, what time period it was from and wrote that down. And then, there was a cheat sheet that went along with the rocks, and I wrote the location down, where it was found and the sample number and everything. And then we tested it with like the HCL to see if it was like carbonate. And, described it and named it. Anything. I wrote down the hardness for some. Sometimes I wrote down the, actually for a lot of it I wrote down the environment, I looked at the environment in the lab…*

Karen was very successful in expressing how she made use of the data to formulate explanations in her lab reports. Karen's, much like Jake's lab reports, often provided a detailed description of the type of data collected and how it was used to formulate explanations. Karen overall, was very accurate in her interpretations of the data, receiving scores of 92%, 100%, 61% and 97% on her lab reports. The one low grade for Karen's lab reports stemmed from her neglect to answer all the questions on the inquiry assignment.

Although these three students were successful in determining what type of data was needed to address the inquiry questions, all three were not as successful at demonstrating how they made use of the data to formulate their explanations. Contrary to what was observed in the classroom, in which Jackson, Jake and Karen were actively engaged in formulating explanations from what they were observing, for Jackson in particular, this did not always translate to their written inquiry-assignment reports. However, with a few exceptions, the students demonstrated a high degree of accuracy in interpreting the data, suggesting that they indeed were learning the necessary course content.

Evaluate explanations in light of alternatives.

Two questions were used to analyze student engagement with this inquiry process: (1) Did students gather and draw on background information, consider alternatives, and make predictions?, and (2) What resources did students use?

Evidence collected suggests that students in this geology class spent the majority of their time engaged in this inquiry process. Jackson, Jake and Karen were observed spending a significant amount of time making predictions about the identity of a sample and considering alternatives for what they believed a sample to be. This is also evidenced in the types of questions these students were observed asking to their peers, TA and instructor.

Jackson, Jake and Karen made selective use of resources to aide their completion of inquiry activities. Despite the fact that students were provided with access to Internet resources, including access to DLESE, they rarely made use of them. Instead the most commonly used resource was the textbook. Other resources used included *Paleonotes,* locality maps, and pictures that often accompanied the samples presented in the lab.

Jackson.

Jackson was able to appropriate this inquiry skill particularly well. From classroom observations of Jackson, he engaged in a significant amount of predicting the identity of a sample, and while working with other students, considered alternative explanations. The following is a brief sample interaction observed while he was completing the first lab exercise:

> *[Working on identifying Sample T8]*
> *1:26*
> *Jake – what's this green chunk?*
> *Jackson- It could be ….I can't think of the word*
> *Melanie – Iron?*
> *Jackson - Lets put some acid on there.*
> *[they do – it bubbles]*
> *Jackson – Its carbonate. [Says to Jake]: Did you taste the rock bro?*
> *Jake - Yeah it tastes gritty.*
> *1:30*
> *[Everyone looking through Paleonotes – presumably to find information to help them identify the rock]*
> *1:31*
> *Jake: We found the stromatotlites east of this so maybe its ____?*
> *Jackson: The green section could be cretious which is part of the Cretaceous period*
> *[Group continues looking at rock and handout]*
> …

This example shows Jackson engaging in prediction while using the tools of geologists (e.g., the HCL test) to test alternative hypotheses. Finally, Jackson was using data from a previous sample to help shape alternative hypotheses.

With regards to resources, Jackson did not use a significant number of outside resources. Jackson frequently made use of the textbook and *Paleonotes.* However, he rarely made use of Internet resources, including DLESE, because he was not comfortable with computer use.

Jake.

Jake also engaged actively in this inquiry process. As already mentioned, Jake commonly engaged in prediction questioning with both his peers and the instructors. The following is an example of an observed interaction between Jake, Jackson and Dr. Sanders that demonstrates Jake engaging in prediction and considering alternatives.

Dr. Sanders: Could you determine if it was from a marine environment if you just had this rock, without all this other information?[indicating to the outcrop picture and map locality] Can you tell the facies?
Jake: Maybe it's from a delta because that's where outcrop meets the ocean.
Jackson: I thought this exhibited graded bedding.
Dr. Sanders: What would be the characteristics of a bed? Do you remember any terms? What causes this kind of form? [indicating to the rock]
Jake: Erosion?
Dr. Sanders: Yes
Jackson: What's the scale?
Dr. Sanders: That's a good question. If you were out in the field it would really stand out at you. Use the picture of the location. Hand samples can only tell you so much. You are on the right track.
12:28
Dr. Sanders leaves.
12:29
Jake: Maybe it's from a glacial lake.
12:30
Melanie: What about an alluvial fan?
…

Jake also frequently made use of his textbook and the *Paleonotes* to complete the inquiry assignments. However, he expressed dissatisfaction with the search mechanism of DLESE and thus, made very little use of the digital library throughout the semester. Jake did however, make use of other Internet resources, stating that he had a list of geological websites that he preferred accessing rather than DLESE for his geological information.

Karen.

Although Karen most frequently worked collaboratively with Jake to complete her inquiry assignments, she was not as vocal as Jake in the lab setting. Karen appeared to be engaged in discussions during which her peers considered alternatives however, she was not vocal, and thus it is difficult to assess how well Karen was able to appropriate this skill.

Karen frequently made use of the textbook and *Paleonotes* as resources. Karen, was also an avid user of DLESE at the beginning of the semester, but due to challenging experiences using DLESE (e.g., lack of relevant resources), as the semester progressed her use of the digital library declined.

Thus it appears that Jackson and Jake were quite successful at engaging in the inquiry skill of evaluating explanations in light of alternatives, while unfortunately there was not enough evidence to accurately assess how well Karen was able to appropriate this skill. Additionally, students made selective use of a number of resources, although DLESE was not amongst their favorites.

Communicate and justify proposed explanations.

The two questions that were the focus of analysis for this inquiry process were: (1) How did students present their conclusions?, and (2) Did students use data to justify their conclusions? Overall, Jackson, Jake and Karen became increasingly competent in this skill, becoming more familiar with scientific discourse and methods for presenting their findings. With detailed feedback from Dr. Sanders, Jackson, Jake and Karen were able to appropriate this skill very well.

Jackson.

Jackson typically presented his conclusions in the form of a typed report. In fact, Jackson was the first student to follow the "scientific-report" method, which prompted Dr. Sanders to encourage other students to utilize this format for their subsequent lab reports. While Jake and Karen were quite adept at using their data to justify their conclusions from the very beginning, for Jackson, it was a developmental process. From the first reports, Jackson often did not support his conclusions using the data he had collected. This is directly related to the issue he discussed regarding not providing enough 'detail' in his responses. However, as the semester progressed, Jackson became familiar with the inquiry expectations and adept at including the necessary details to support his conclusions.

Jake.

Jake typically presented his conclusions in a typed report that employed high quality writing. Jake, from the beginning utilized his data to justify his conclusions in his lab reports. He was very skilled at writing and justifying his explanations, making explicit reference to data that he had collected during the lab. Here is one example of Jake's writing style:

> *…All of the fossils that were categorized into the phylum Chordata consist of phosphatized bone, free from sediments. Unlike other hard parts in the suite of 30 [rock samples], these bones did not react with HCL, as they had not been constructed from calcium carbonate or had their original material replaced with it. One sample, 13, was of a large, internally porous fossil bone. This internal porosity is characteristic of the inside of chordate bones…It would seem from these three samples that chordate bones are usually preserved as unaltered hard parts, with varying degrees of fossilization dependent on age and other factors…*

Karen.

Karen typically presented her conclusions in a typed report employing high quality writing. Karen was also very skilled in this aspect of inquiry. She most often made explicit reference to her data, and would often include additional figures and tables to illustrate her ideas. Karen often demonstrated exemplary work. Here is an excerpt from Karen's Lab 2 report:

> *…In the second work station, my group and I looked at thin sections that may or may not have had living matter in them. Using the criteria we developed in the first work station, each slide (B-7, B-10, and 29-49) contained a life form. In addition, I sketched each sample, using a representative from each of the slides (See Figure 1). The samples from each slide had a cell structure, as well as order to the structure. Those were the two*

> *components from our criteria list that we used to determine that each samples [sic] was indeed a life form…*

Thus, both Jake and Karen quickly mastered this inquiry skill, demonstrating very little difficulty with communicating and justifying their explanations. However, for Jackson this was again a developmental process, in which he showed improvement as the semester progressed.

The above results provide a glimpse into how students in an inquiry-based undergraduate geology course engaged in, and appropriated inquiry skills. Overwhelmingly, Jackson, Jake and Karen demonstrated that they were quite capable of engaging in inquiry activities, successfully engaging in questioning, giving priority to evidence, formulating explanations, evaluating alternatives and communicating and justifying their explanations. While Jake and Karen displayed a high degree of facility with the inquiry skills early in the course, Jackson showed improvement in his ability to engage in components of the inquiry processes of *formulating explanations from evidence* and *communicating and justifying explanations*, as the semester progressed.

It should be noted however, that the experiences of Jackson, Jake, and Karen were not typical of the experiences of all the students enrolled in the course. Rather, based on the analysis of available data, Jackson, Jake, and Karen, were the students most successful at appropriating and engaging in inquiry. Robin, who did not serve as a case for this study, also demonstrated some success in appropriating and engaging in inquiry activities within the course. Unfortunately, based on the available data, the other students (Drake, Kyle, and Melanie) were much less successful engaging in inquiry. However, the reasons and rationales for the limited ability of Drake, Kyle, and Melanie to engage in inquiry practices are beyond the scope of this paper.

Although Jackson, Jake and Karen demonstrated remarkable success in this inquiry-based geology course, this success was not without its struggles. In the next section, results related to students' challenges engaging in inquiry are presented.

Research Question 2: *What challenges do students experience with engaging in inquiry processes in an undergraduate inquiry-based geology course?*

At the beginning of the semester, the most common challenge Jackson, Jake and Karen expressed having with engaging in inquiry processes was the shift from having an instructor or TA that acted as a deliverer of knowledge, to one who acted as a facilitator or guide to their learning. As a result of this, these students expressed frustration, feeling they did not have enough knowledge to effectively engage in inquiry processes. In addition, they felt that they were sometimes left with too little guidance or support while constructing their knowledge. Although these students valued the knowledge that the TA had to offer, they sometimes felt that he was not providing them with the kind of support that they needed.

During his first interview, Jackson expressed the following sentiments about the inquiry-based labs:

> *They've been a little bit more confusing this year it seems like. Because last year, it seemed like if we were in lab and asked a question. And we were like "Okay, we're thinking that this rock is this." If we were right, our TA would say "Alright, great job!" Instead it seems like [the] TA kind of is like "Yeah" even if we are right he'll say "Yeah, but have you thought about this?" on a completely different direction. And we'll talk about it for 15 minutes and then we'll come back to the first thing we were at and he's like "Yeah, yeah you know that's a pretty good job right there, that ought to cover it." It just seems like he, I mean I know he means well. And he's trying to get us to think about all the different aspects of approaching things but, I mean, c'mon! I think if I'm right, I should just be right and commended for it. Other than, it seems like he's trying to confuse us. But other than that it's going great. It just gets a little frustrating I guess…*

Likewise, Jake expressed similar feelings of frustration with what he perceived to be a lack of support during completion of the inquiry assignments. Jake talked about how he felt that his lack of background knowledge was posing a significant challenge in his being able to effectively engage in inquiry processes.

> *I noticed that there is a lot of um, 'We don't want to help you very strongly' or 'We don't want to lead you because we want you to figure it out for yourself' going on. And that's fine. I can totally like see that teaching style, but in a class like this – we don't have, we're just, I've only had 2 geology classes, so has every other geology major in that class, well I wouldn't say that, most every other geology major in that class has only had 2 classes. So I, a lot of times I want to be taught like a little more – here it is, learn this, here is a tool for you to use when your looking at this particular thin section. In the lab the other day we had a thin section and me, Melanie, Jackson, and Karen sat there for about 1 hour and 1/2 trying to figure out what it was. And me and Karen, had never looked at a thin section before. Its not like it's a big revelation. But I mean this is the first time we had done it. We didn't really, we weren't sure what the mineral grains were, if it was like a creature of some sort. And we were trying to get help with that, we just didn't know what we were looking at and everyone was trying to like stay away from anything that could possibly help us and just try to get us to think of it for ourselves. But my contention is that we didn't have like the necessary tools to evaluate it to start off with…*

Karen expressed similar sentiments as Jake, stating:

> *Sometimes in class we'll be working as a group and we'll you know get stumped on something, and we try to ask like the TA or Dr. Sanders and sometimes we just aren't really giving us the right information to figure out the problem and its just hard because we have no idea what we'll be doing and we just can't really work the way they want us to because we just don't have a clue. It, I feel like we don't have all the information. Since I guess we're still relatively new at this, so I don't think we have the background that they do so I guess maybe its hard for them to you know remember that. And maybe give us some more clues or maybe step back and think about how much we know, how little we know and I guess just go from there to help us. Or maybe like tell us the answer and then work backwards like how they found that answer. Because its hard to go from like no information to like figure out the answer.*

Thus, for these three students who spent the majority of their time engaged in the inquiry process of *evaluating explanations in light of alternatives*, their perception of their own lack of background knowledge as well as the perceived lack of support or guidance from the TA, constituted a significant challenge, and one that has implications for future instructors of inquiry-based science courses. In any inquiry-based course it would be expected that for an instructor new to inquiry-based teaching techniques, as was the TA in this course, that improvements in their ability to guide student engagement in inquiry processes could be expected over the time of the course. As illustrated below, students were divided in their judgments regarding the degree to which the TA's capacity to support inquiry-based learning improved during the course.

Early in the semester, Dr. Sanders recognized some of the difficulties that both the TA and students were having adjusting to the inquiry-based approach. With respect to the students, Dr. Sanders recognized some of the frustration students were experiencing in the lab:

> *They may be more frustrated. I see them fishing for answers – 'Well, what is the name of this rock?' You know, just take me off guard right. And I said 'Oh, well you're supposed to figure that out.' But they're still trying to operate on the old systems of give me the answer. And I'm trying hard not to do it like that.*

Dr. Sanders was also very aware of the importance of the TA's role for facilitating student inquiry. Dr. Sanders recognized the necessity to mentor the TA, to help him develop the skills necessary to better facilitate student inquiry:

> *I remember one interaction with the Lab 1 last week and he [the TA] was trying to give them the answers, and I was listening, and I interrupted, hopefully gently, to say well what are the alternatives hypotheses, or I don't remember exactly, but I was trying to get them to think differently about it, and think about this and think about that…And so I was trying to show him how I would do it. And I think he's starting to learn that…*

The TA recognized his need to develop the skills necessary to better facilitate student inquiry as an instructor. During his first interview, the TA discussed his prior experiences with inquiry-based learning approaches. Although he had participated once as a student in an inquiry-based course, the TA had very little prior experience facilitating student learning in an inquiry-based environment:

> *…I've never tried to teach an entire course as inquiry-based learning but I think I know something about it at least having taken it as a student…But as far as trying to set it up to teach, that's something that I want to do more of but at the same time know I'm not yet comfortable with, and I guess that's because I haven't done enough of it, just learning how to set it up and engineer it to steer them well. So I need to learn more about it before I can use it that effectively, but at the same time it is something, that is something that I am aiming for…*

By the mid-point of the semester the TA also recognized that some of the students were experiencing frustration in the laboratory, particularly with regards to his facilitation style:

> *I think towards the end of lab everybody gets kind of 'punchy' and I think occasionally they just get frustrated after a while. And I admit I might contribute to that occasionally as far as when I keep asking them 'why do you say this' or 'why do you say that' while trying to remind them occasionally that I am heading in some direction which would be helpful hopefully.*

By the end of the semester, the TA had gained some insight into ways that he might be better able to facilitate student learning in an inquiry-based laboratory in the future:

> *Now that the course is done, yeah there are definitely some things I would probably do differently. Like we talked about once, I think in class as far as my asking, I need to inform them [the students] that they are indeed on the right track before I ask them why they are thinking about things. Then again, that was mentioned by, mentioned in one of my [teaching] evaluations. I forgot how it quite went but something like 'While the TA means well at trying to encourage questions or encourage us to justify our answers it's kind of frustrating because he doesn't tell us whether or not we are headed in the right direction.' So you know, things like that…*

Karen believed that the TA had made progress in developing his inquiry-facilitation skills by the end of the course. During her final interview Karen expressed how her perceptions of the TA and his support for her learning had changed:

> *…At first everybody was having a hard time with him because when you had a question you could have it right but he'd be like "Oh wait, why do you think __?" You know? And make you think you were wrong and then like an hour later you were like "Oh my gosh, I was totally right!" So it was more frustrating than anything. But as the semester like progressed he definitely got better and like, the lab with the vertebrates and something else 2 weeks ago? He helped me out a lot with that lab and like helped me think, and like really, you know in a really productive way. It wasn't hindering like or anything at all…*

Unfortunately, at the end of the semester both Jackson and Jake still felt that the TA's facilitation style posed a challenge to their ability to engage successfully in inquiry practices.

In his final interview Jackson stated:

> *…He's [the TA] really smart but didn't, you know sometimes he didn't help me out the way I wish he would have. I know we talked about that before. It's just kind of frustrating trying to talk to him about anything really. But I know he knows his stuff, I mean he definitely helped us out in a lot of situations but it seemed like there were probably an equal amount of situations where it was just frustrating trying to even talk to him…*

Jake, felt that the TA could be helpful at times, but once again expressed a desire to have more guidance while engaged in inquiry activities, stating:

> *…[the] TA was really good. I liked talking to him on like a, its like he means, its like I know that you are doing like the leading questions, and wanting us to think for ourselves but sometimes there needs to be a line drawn and like say okay this is where you need to look like sort of deal, a little bit more leading is like sometimes okay I think…*

Thus, suggesting that while the TA's facilitation skills may have improved slightly over the course of the semester, it was not a significant enough amount to support all students as they engaged in the inquiry activities.

Yet, despite these perceived challenges, by the end of the semester each of these students demonstrated that they were able to successfully engage in inquiry processes. For Jackson, the development of these skills appeared to be the greatest. Although his grades on his inquiry lab reports were wide ranging, and his score on the inquiry-based midterm exam was low (73%), his improved performance on the inquiry-based final exam (83%) demonstrated his development and his ability to successfully engage in inquiry. Jake, demonstrated a high level of ability to engage in inquiry processes right from the beginning of the course, and thus the development of his ability to engage inquiry was likely not that significant. Jake performed extremely well on the midterm exam (96%), however his performance on the final exam was well below his ability (79%). When asked about his performance on the final exam Jake remarked:

> *I feel like my grade on the final was fair but I got, I think I got like a 79 on it. I don't feel like it's a fair representation of what I learned in the course, because the reason I scored so low was because I was like out of time. And… the last 2 pages or so of my like paper*

> *weren't very good at all. There was like this one section where we had to like bring together all the evolutionary trends over, that were displayed in the data we had and I uh, I like, when I got to that section I didn't have time to do it well, as well as I wanted to. That's where I got pretty much all my points off… I think I would have had like an 87 if it hadn't been for that…*

For Karen, although she performed well fairly consistently on the inquiry lab reports, her performance on the midterm exam was lower than she expected (80%). However, she demonstrated on the final exam (94%) that she too had successfully appropriated many of the inquiry skills necessary to engage in scientific inquiry.

Overall, with respect to the final performance of all students enrolled in the course, Karen and Jake emerged as the top performers. Both Karen and Jake received the only two grades of A given in the course, while Jackson received a final grade of B (one of four total B's given). Thus, clearly Jake and Karen's ability to appropriate and engage in inquiry practices translated to being successful academically in the course.

Discussion and Implications

This research has provided a much-needed description of how undergraduate science (geology) majors engage in inquiry processes in an inquiry-based course. The benefits of engaging in inquiry are well documented, however inquiry-based teaching and learning approaches pose challenges for both instructors and students (Krajcik et al., 1998). Studying students' engagement in inquiry processes can help direct practitioners and researchers to ways in which students' inquiry experiences can be improved. The ways in which students were successful, and where they had challenges appropriating inquiry practices is discussed in the following sections.

Engaging in scientific questioning

The ability to ask scientific questions is a central tenet to learning through inquiry, thus instructors should aim to create effective learning environments in which students are given opportunities to ask relevant scientific questions (Hofstein, Shore, & Kipnis, 2004). The students in this study were given a scientific question to pursue as part of each inquiry activity. However, it was of interest to the researcher whether these students would develop alternative scientific questions en route to answering the inquiry question, and if so, what the nature of these questions would be. The types and number of questions that the students raised were wide ranging, however there was limited evidence of any changes in the ability to ask additional scientific questions, or in the types of questions asked. Unlike, previous studies (e.g., Hofstein, Shore, & Kipnis, 2004) in which with increasing experience with inquiry-based learning students showed significant change in the types of questions they asked, the students in this study showed no such evolution.

The ability to be able to verbally participate in inquiry activities by asking questions or collaborating with others to formulate explanations, or justify conclusions is an important skill. So why did these students not engage in significant questioning beyond the requirements of the inquiry assignments? Clearly, these students were given sufficient opportunities to ask questions. The limited number and relatively superficial types of questions students were observed asking seemed to stem from their personal learning preferences or desires. For students who are accustomed to being passive participants in their learning, this inquiry skill may pose a challenge for them. Alternatively, the students may have perceived the assignments as tasks to be completed in an academic sense rather than authentic research activities that engaged their scientific curiosity. In other words, they may not have come to "own" the inquiry.

Regardless of the reasons for why they did not engage in deeper questioning, this study suggests that undergraduate students need scaffolding to learn how to generate questions to explore information related to the inquiry questions (Krajcik et al., 1998).

Ways of moving them from an academic approach to completing inquiry assignments to a more authentic science approach must be found. More research that investigates ways to facilitate and scaffold active student participation in posing scientific questions is needed.

Giving priority to evidence

Unlike middle school students who demonstrate difficulty systematically collecting data (Krajcik et al., 1998), the students in this study had very little trouble with this inquiry skill. These results are contrary to research with middle school aged children that suggests that they collect insufficient or inadequate data (Kanari & Millar, 2004). The students in this study also made appropriate use of charts and tables, demonstrating that they were able to transform their data in ways that enhanced their understanding of the data they had collected. It appears that previous geology courses adequately prepared these students to fulfill this aspect of inquiry-based learning.

Formulate explanations from evidence

Although the students were competent in deciding what type of data to collect, and systematically collecting that data, the students experienced more difficulty formulating explanations from evidence. Research suggests that although middle school aged children are able to design and carry out simple investigations, they often state conclusions that are inconsistent with or are not warranted by their data (Kanari & Millar, 2004). Although, the students in this study occasionally made incorrect interpretations of their data, this did not seem to be the crux of their difficulty. Rather, difficulty for some of the students seemed to stem from their inability to express in writing what they often times were able to express verbally.

Research with eighth-grade students suggests that the use of a writing heuristic can facilitate students' ability to generate meaning from data, thus making connections between procedures, evidence and claims (Hofstein, Shore & Kipnis, 2004). Thus, it may have been beneficial to utilize more direct instruction in strategies for generating explanations, or perhaps the instructor could have modeled this on more occasions. Alternatively, scaffolding of this outcome could have been provided in the form of examples of exemplary lab reports to help foster students' abilities to express in writing the connection between their data and explanations.

Evaluate explanations in light of alternatives

The students in this study spent a significant amount of their time engaged in this inquiry process. This finding supports research conducted in an inquiry-based undergraduate biology laboratory in which students spent a large amount of time deliberating and discussing possibilities (Glasson & McKenzie, 1998). The propensity for students to engage in this inquiry practice, may be due to the nature of the subject matter, in which the consideration of a number of alternative processes or environmental conditions is necessary when trying to identify a sample rock or fossil. Thus, based on classroom observations it can be said that the students in this study were very successful at appropriating this inquiry skill.

Interestingly, although the students felt that they were sometimes lacking in the knowledge necessary to complete the task, they rarely if ever made use of outside resources, such as those that could be found in the digital library. Rather, they relied on information they could access in their textbooks, from other students, the instructor, or from the TA.

For these students, the perceived lack of guidance from the TA emerged as the most significant challenge to engaging in this inquiry process. As described above, each student experienced some level of frustration from interactions with the TA. The role of the instructor or TA in an inquiry-based course is critical because without appropriate teacher support, students can become frustrated with the difficulties of reaching scientific understanding alone (Clough, 2002). For this TA, like many others, learning to facilitate students' inquiry activities was a learning process.

Creating an environment conducive to engaging in inquiry requires that an instructor learn among other skills: how to ask effective questions, incorporate appropriate wait time, listen carefully, acknowledge and play off student ideas, exhibit positive nonverbal behavior (Clough, 2002), answer questions with questions, encourage students to think on their own, and supply students with the tools to solve a problem, rather than solving the problem for them (Glasson & McKenzie, 1998). Thus, instructors need not only strong subject-matter knowledge and strong pedagogical content knowledge (knowledge of how to teach the content), but they also need strong *pedagogical content knowledge for disciplinary practices* if they are to effectively facilitate student engagement in inquiry activities (Davis & Krajcik, 2005). That is, instructors need to develop the skills and knowledge for helping students understand the ways that knowledge is generated in a discipline, as well as the beliefs that represent a deep understanding for how the discipline works (Davis & Krajcik, 2005).

Communicate and justify propose explanations

The ability to draw and justify conclusions requires sophisticated thinking with which students from middle school through graduate school may be expected to have difficulty (Krajcik et al., 1998). The students in this study showed varying levels of competence with this inquiry process initially, but all made great strides by the end of the course. Difficulties with this inquiry skill did not appear to stem from lack of scientific knowledge, but rather a difficulty in expressing their knowledge in an appropriate scientific form. However, with feedback from the instructor and TA on their final lab reports, students developed proficiency with this inquiry skill by the end of the course.

Overcoming the challenges to engaging in inquiry

There are a number of possible explanations for why Jackson, Jake and Karen were able to successfully engage in inquiry processes, despite the perceived challenges of lack of guidance or support and insufficient background knowledge. One explanation may be that these students were only experiencing what may be termed 'growing pains' in the process of appropriating and engaging successfully in inquiry activities. That is, because students are used to interacting with their instructors and TA's in particular ways, i.e., asking a question and receiving a direct answer, when the rules of interaction change, students may become resistant to it.

Alternatively, for many students, an inquiry-based learning approach may be a new and uncomfortable experience, thus more scaffolding and guidance may be required at the beginning of a course than at the end of a course when students have become familiar with inquiry. It may be the case that indeed, not enough guidance was provided for these students at the beginning of the course, leading to unnecessary feelings of frustration with learning and course instructors. On the other hand, perhaps a certain level of discomfort is inevitable and even desirable if it shakes students out of their typically passive stance. Further research examining how much, and what types of guidance or support is optimal in these types of learning environments would be beneficial.

Final Words

It is hoped that this portrayal of the behaviors of undergraduate students in inquiry-based learning will inspire other geosciences instructors to incorporate these methods into their own teaching. For the most part, these three students appeared to truly engage in inquiry processes, rather than superficially engaging in the science activities, thus lending support to the notion that inquiry-based learning approaches can, and should be utilized in undergraduate science courses.

However, as desirable as the outcomes of this course were in terms of inquiry-based learning, challenges remain. For example, the results suggest that the amount of guidance and scaffolding provided by instructors is an important component of an inquiry-based learning environment that can be enhanced. For instructors and TA's in undergraduate science courses that employ inquiry-based teaching methods, adjusting to a new role in the classroom (i.e. knowledge-facilitator vs. knowledge- deliverer) is one that may prove to be difficult, but is necessary to encourage engagement in inquiry by their students with a minimal amount of frustration.

Future research directions could include additional qualitative studies such as this one, which would provide more knowledge and insight into the course design factors that can support student appropriation and engagement in inquiry activities. Studies that examine and report on behaviors of students who are less-successful at appropriating and engaging in inquiry activities would help provide a clearer picture of how undergraduate students engage in inquiry activities. Additionally, future research should seek to reveal the underlying cognitive skills required for engaging in inquiry-based learning. Finally, it would be especially interesting, albeit challenging, to utilize these methods in a large section introductory level geosciences course. Success at that level would go a long way in overcoming the resistance to these methods that is evident in many undergraduate science programs today. Studies such as these are necessary if we are to begin to help practitioners and researchers create learning environments that can take full advantage of the pedagogical strategy of inquiry-based learning.

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CHAPTER 5

INTEGRATING INQUIRY-BASED LEARNING INTO AN UNDERGRADUATE GEOLOGY LABORATORY: GUIDELINES AND LESSONS LEARNED[1]

[1] Apedoe, X. S., Walker, S., & Reeves, T. C. To be submitted to the *Journal of Geoscience Education*

Abstract

This paper presents a strong rationale for incorporating inquiry-based learning as the defining pedagogy in an undergraduate geology course. In addition, the paper describes eight dimensions of any undergraduate course (course objectives, course content, pedagogy, task characteristics, instructors' roles, students' roles, technological affordances and assessment strategies) that must be aligned to ensure the validity of the design and implementation of inquiry-based learning strategies in undergraduate course. Qualitative data from a semester long investigation of the implementation of such a course is provided to illustrate the importance of aligning these dimensions. The paper concludes with recommendations for undergraduate instructors wishing to adopt such an inquiry-based learning design themselves.

Integrating Inquiry-Based Learning into an Undergraduate Geology Course: Guidelines and Lessons Learned

[G]eology is both a body of knowledge and a way of thinking and doing things. That is, there are things that we do operationally as well as things we know. Often in undergraduate education there is a tendency to emphasize the knowledge but not the way of thinking and doing.

(Buchwald, 1997, p. 327)

Blueprint for Change: A Report from The National Conference on the Revolution in Earth and Space Science Education (Barstow & Geary, 2002) details a new vision for teaching and learning in the earth sciences. *Blueprint for Change* advocates adopting a science as a verb perspective, emphasizing "the human endeavors, successes, failures, and emotional dispositions associated with doing science as inquiry" (Yore, Florence, Pearson, & Weaver, 2002, p. 5), rather than the science as a noun perspective, which stresses textbook knowledge, lists and procedures about scientific processes. Geosciences educational experiences should help students develop thinking skills such as inquiry, visual literacy, understanding of systems and models and the ability to apply knowledge and problem solving to a range of substantive, real-world issues (Barstow & Geary, 2002). To accomplish such goals, *Blueprint for Change* recommends that science educators emphasize using inquiry-based learning and visualization technologies in the classroom, laboratories, and other environments to promote understanding of the earth as a system.

The purpose of this paper is to provide practical guidelines to instructors of undergraduate geoscience courses who wish to integrate inquiry-based learning into their teaching. We begin with an overview of inquiry-based learning, then we present a framework that can be used to design a course that incorporates inquiry-based learning. Next, we present a description of a specific case of integrating inquiry-based learning into an undergraduate geology course as well as the results and lessons learned from the experience.

Background

Inquiry-based learning and teaching

The use of inquiry-based learning has received much attention since the National Research Council (NRC) released the National Science Education Standards (NSES) (National Research Council, 1996) for K-12 education. Inquiry describes the "diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" (National Research Council, 1996, p.23). Inquiry also refers to the activities of students "in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (National Research Council, 1996, p. 23). Thus inquiry describes both a process that scientists use to investigate phenomena in the natural world, as well as an instructional methodology that can help students achieve understanding of scientific concepts and practice and participate in activities typical of working scientists.

A number of studies have reported the benefits of inquiry-related teaching approaches, suggesting that inquiry teaching techniques foster among other competencies, scientific literacy, understanding of scientific processes, and critical thinking (Cavallo, Potter, & Rozman, 2004; Glasson, G. E., & McKenzie, 1998; Haury, 1993). Inquiry-based teaching approaches can also improve students' understanding of the scientific method and its strengths and weaknesses (Keller, Allen-King, & O'Brien, 2000). These and other studies imply that the use of inquiry-based learning is an effective approach for teaching science at all levels ranging from K-12 through undergraduate education (National Research Council, 2000).

Indeed, although the NSES focus primarily on science teaching and learning in K-12 education, McIntosh (2000) maintains that the recommendations for reform can and should be applied to college-level science courses. College science instructors are responsible for fostering the development of students': (a) scientific knowledge, (b) understanding of the nature of science, (c) ability to appropriate and understand scientific ways of thinking, and (d) ability to make connections between their learning and the outside world (Siebert & McIntosh, 2001). Thus, college science instructors can play an integral role in leading science education reforms. College science instructors can create inquiry experiences that can range from problem-based learning situations in which students engage in solving real world problems to inquiry-based labs in which students are able to design and conduct their own scientific investigations (McIntosh, 2001).

Utilizing inquiry-based methods in university and college science classrooms may become more important than ever if the reforms in science education at the K-12 level are successful and students begin to enter college and university with strong inquiry skills and raised expectations for being engaged in science based upon their experiences in lower grades. Although the evidence that such reforms are working as intended has not yet been provided, it seems wise for college and university science instructors to begin to adapt their teaching approaches accordingly. The coordination of science learning experiences across K-16 may result in more effective teaching and learning, easing the transition for students across grade levels (National Science Teachers Association, 2000). In order to begin this transition, college science instructors must be aware of the reform efforts occurring in K-12 science education, as well as how the knowledge base that supports it can inform their teaching practice (McIntosh, 2000).

Inquiry-based Learning and Geoscience Education

Inquiry as a teaching methodology and learning experience emphasizes providing students with opportunities to participate and practice the activities involved in science. When learners are engaged in inquiry-based learning environments they should (National Research Council, 2000):

- Be engaged in scientifically oriented questions
- Give priority to evidence, allowing them to develop and evaluate explanations that address scientifically oriented questions
- Formulate explanations from evidence to address scientifically oriented questions
- Evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding
- Communicate and justify their proposed explanations

These five elements are essential characteristics of an inquiry-based learning environment.

Although it certainly sounds good in theory, adhering to the recommendations for reform outlined by the National Research Council has proven to be quite difficult for educators working in K-12 environments, posing as it inevitably does issues related to the balance of content, thought processes and teaching strategies (Oliver-Hoyo, Allen, & Anderson, 2004). Although there have been a number of undergraduate geoscience educators that have utilized inquiry-based teaching methods in their courses (Keller, Allen-King, & O'Brien, 2000), integrating inquiry-based teaching methods in undergraduate science instruction may be even more difficult than integrating inquiry methods into K-12 learning environments. For undergraduate geoscience instructors, integrating inquiry-based pedagogy raises issues of 1) finding time to shift pedagogical styles, 2) choosing content to exclude in order to accommodate time-intensive inquiry approaches, and 3) developing the background and skill with using inquiry-based instructional strategies (Field, 2003). Despite these challenges, engaging students in inquiry activities throughout their undergraduate careers is of utmost importance if students are to graduate with the types of 21st Century outcomes that are expected such as robust scientific mental models, the capacity for solving ill-structured problems, sustained intellectual curiosity, and a commitment to lifelong learning (Hersh & Merrow, 2005). In addition, engagement in inquiry at the undergraduate level promises to help prepare students for further education experiences such as graduate school, or later professional opportunities (Field, 2003).

Aligning Critical Pedagogical Dimensions in an Inquiry-based Geoscience Laboratory

There are multiple dimensions that must be aligned when designing and implementing any learning environment such as an undergraduate Geosciences course (Reeves, 1994; Wang & Reeves, 2003). At a minimum, these dimensions include: course objectives, course content, pedagogy, task characteristics, instructors' roles, students' roles, technological affordances and assessment strategies. Thus, when utilizing an inquiry-based pedagogy that supports the five essential characteristics of inquiry-based learning (i.e., learners engaged in scientific questions, giving priority to data, formulating explanations, considering alternatives, and justifying explanations), it is of utmost importance that the seven remaining dimensions are in alignment with this pedagogical design. Table 5.1 provides a description of each dimension, and describes how these dimensions can be characterized within the context of an inquiry-based pedagogical framework. Failure to align these dimensions will undermine the successful design and implementation of an inquiry-based pedagogy into an undergraduate geoscience course. To illustrate the successful alignment of these dimensions, a specific case of integrating inquiry-based learning into an undergraduate geology course is described below.

Table 5.1: Critical Pedagogical Dimensions within an Inquiry-based Science Course

Dimensions	Characteristics	Characteristics within an Inquiry-based Pedagogical Framework
Course Objectives	• Knowledge, skills and attitudes that students should develop as a result of participating in the course. • Ideally stated as measurable outcomes ranging from discrete knowledge to higher order thinking.	• Students should develop knowledge of scientific ideas and the scientific process. • Students should develop the skills necessary to participate in scientific activities.
Course Content	• The information and data that encompass the subject matter to be taught, studied, and learned in the course. • Includes the format information is presented in (e.g. highly structured formats such as textbooks).	• Within an inquiry-based course, content should be accessible in ill-structured, real-world formats such as the data from remote sensing satellites.
Pedagogy	• The instructional approach or methods used in the course. • Can range between direct-instruction with a heavy emphasis on lecture, to constructivist approaches with an emphasis on problem/project-based learning.	• Provides learners with the opportunity to: engage in scientific questions; gather evidence, formulate explanations, evaluate alternatives, and justify explanations.
Task characteristics	• The strategies used to engage students in meaningful learning activities.	• Spells out the nature of the inquiry activities that students are to complete with respect to their investigation of an authentic scientific problem. • May engage students in inductive problem-solving akin to the work of real-world scientists.
Instructor's roles	• The mode of interacting with students. • May range from a didactic teaching mode where instructors deliver prepackaged information to students, to instructors providing scaffolding (or support) functions while students are engaged in tasks.	• Instructors provide scaffolding (or support) while students are engaged in realistic inquiry. • Instructors resist the urge to jump in and complete tasks for students as students grapple with complexities of authentic inquiry tasks.
Students' roles	• The active cognitive, psychomotor, affective, and conative (Snow, Corno, & Jackson, 1996) interactions in which students will engage as they grapple with tasks, content, co-learners, the instructor, and other components of the learning environment.	• Requires students to be active participants in their learning. • Typically involves collaboration among students, just as science requires teamwork.
Technological affordances	• The interaction possibilities posed by technology used to support learning in the learning environment.	• Technology can provide students with access to the types of tools and data that working scientist typically use.
Assessment strategies	• The methods used to estimate student accomplishment of the course objectives.	• Assessment is based upon observations of student engagement and analysis of documents such as research reports. • Requires the assembly and critical analysis of multiple forms of evidence that learning outcomes have been attained.

Course Design

Background Information

During the 2004-2005 academic year, an instructional technology doctoral student (first author) and geology professor (second author) at a large research university located in the Southeastern USA collaborated in the redesign of an undergraduate course. The impetus of this course redesign was two-fold. First, the instructor of the course expressed a concern about previous students' performance on her inquiry-based exams. After meeting and discussing the components and goals of her course, the instructor and the primary researcher determined that a re-design of the laboratory component of the course was necessary to be more consistent with inquiry-based outcomes she expected. The instructor, who was familiar with inquiry-based approaches for teaching and learning, had been utilizing inquiry-type exams, but had not frequently engaged her students in inquiry-based activities prior to the exam. Thus, students typically performed poorly on the exam, likely because they had insufficient prior experience with inquiry-based activities and had a difficult time ascertaining what was expected of them.

Second, the research team was interested in investigating how a digital library developed specifically for the earth sciences could be used by instructors and students to support teaching and learning in an inquiry-based geoscience course. Two members of the team (first and third authors) were already involved in the evaluation of the Digital Library for Earth Systems Education (DLESE), and accordingly it was decided that DLESE would be incorporated into the re-designed laboratory component of the course.

The Design Process

The instructor and the instructional technology doctoral student met regularly throughout the summer of 2004 to plan and design the course, which was implemented in

Fall 2004. The design process began with a discussion of the instructor's goals for the course. Each of the lab assignments that the instructor had used in previous years was reviewed and prioritized based on the topics the instructor believed most important for hands-on inquiry experience. Then, each lab revision began with the instructor envisioning what her 'dream' lab might involve. What activities would she engage students in if there were no constraints? What would she want students to learn from the lab? Then, after discussing the essential characteristics of inquiry-based learning activities, the instructor either re-designed a lab activity that she had used in the past, or created a new activity to address the learning goal she deemed important for students to learn. Thus, the instructor was the primary designer of the lab activities, while the doctoral student served in a consulting role, providing feedback and suggestions for creating activities consistent with inquiry-based learning goals. This design process was used to create a set of 8 labs, requiring students to engage in various levels of guided and open inquiry activities. Although, all the lab activities were designed prior to the start of the semester, the research team agreed that the lab activities could, and should, be adjusted as needed based on student performance and feedback throughout the course.

Course Description

The course was an upper-level undergraduate geology course consisting of 2 hours of lecture and 3 hours of lab per week. Lectures were held twice a week, with the lab occurring directly after the second lecture meeting.

Course Objectives. The learning goals as stated on the course syllabus were:

> *To understand the major events in biotic evolution from Precambrian to Phanerozoic time and learn applied aspects of paleoenvironmental analysis and relative age-dating using fossil organisms. To achieve these goals, scientific critical thinking, presentation and writing skills will be emphasized.*

To this end, it was expected that students would (a) develop the skills necessary to participate in scientific inquiry processes related to geological inquiry, and (b) develop deep understanding of the relevant geology content (e.g., to help students learn the applied aspect of paleoenvironmental analysis and relative age-dating by using fossil organisms).

Course Content. The course focused on principles of paleobiology, including biostratigraphy, paleoecology, taphonomy, and macroevolutionary dynamics. Content for the course was presented in a manner consistent with inquiry-based pedagogical approaches, that is, in the form of real data such as the numerous rock and fossil samples with which the students interacted in the process of solving an applied geology problem. In addition, students were encouraged to access dynamic and static resources in a digital library specifically developed for the geosciences, the Digital Library for Earth Systems Education (DLESE – available at: http://www.dlese.org). Students also had access to more highly structured information, such as that found in their textbook.

Pedagogical Design. As described above, the primary pedagogical strategy for the lab portions of this course was hands-on inquiry based learning activities wherein students were challenged to solve authentic geology problems. Table 5.2 provides a listing of concepts addressed in each inquiry-based lab assignment.

Inquiry Tasks. The inquiry tasks were structured according to guidelines for creating inquiry-based learning environments suggested in the NSES. Variations in the amount of learner self-direction and direction from the teacher and/or learning materials, characterizes each inquiry-based learning task as more "guided" or "open" (National Research Council, 2000). Guided inquiry is used to support learning goals related to the development of scientific concepts, while open inquiry is best used to support the development of scientific reasoning (National Research Council, 2000). Each inquiry task developed for this course required students to address an applied geology problem. The following is an example of an applied geology problem that students addressed in Lab Activity 1:

> *Applied Geology Problem – Inquiry Task 1*
> *Rock samples have been collected from the American west, comprising what is now Oregon and Washington, U.S.A. (see map provided).*
> *The Problem*
> *A major problem concerns whether these rock samples provided for this applied geology problem contain any information in regard to plate tectonics --that is, do the rocks indicate the assembly of western North America in any way? Given the suite of rocks, would you conclude that western North America was an active or passive margin? Additionally, do the rocks indicate any major environments that occurred in these areas in the past? You can use the map information to interpret geologic time and/or environments as well. For selected rock types found in this lab, how are they related to the rock cycle?*

Table 5.2: Lab Activities and Concepts

Lab Activity	Concepts
*Lab 1: Rocks as Guides to Tectonics & Environments	Three major rock types; minerals; depositional environments; rock cycles
Lab 2: Biogenicity and Earth's Earliest Life	Biogenicity criteria; Schopf vs Brasier biogenicity debate concerning Apex Chert Microfossils
Lab 3: The Protozeroic Revolution: The origin of Eukaryotes	Eukaryotes; prokaryotes
Lab 4: Micropaleontology: The single-cell grade of evolution (Foraminifera)	Foraminifera; Radiolarians; Diatoms; Coccolithophorids
*Lab 5: Skeletons and The Perils of Preservation	Invertebrate phyla; preservational states, body plans
*Lab 6: Paleozoic Revolution	Comparative paleontology; Phyla Porifera, Phlya Archaeocyathida, Phyla Cnidaria, Phyla Brachiopoda, Phyla Ectoprocta; Phyla Arthropoda; geologic timescale for Paleozoic
*Lab 7: Mesozoic Marine Revolution	Phyla Mollusca (Class Gastropoda, Class Bivalva, Class Cephalopoda)
*Lab 8: Major evolutionary trends in deuterostomes: echinoderms and vertebrates, with special emphasis on the Cenozoic Era	Evolutionary trends in echinodermata; ancestor to descendant relationship in vertebrates

Note: Labs with * indicates a 2-week lab activity.

Instructors' roles. The instructor for this course was very familiar with inquiry-based teaching practices, and thus felt very comfortable acting as a facilitator for students learning through inquiry. However, the teaching assistant (TA) for the course had very little prior experience in facilitating student learning in an inquiry-environment, and thus was less comfortable and skilled in the process. The role of the instructor and the TA changed as the semester progressed. When the instructor had taught the course in the past, the lab was the primary domain of the TA. That is, the TA was typically responsible for setting-up the lab, guiding students through the lab, and grading all lab reports. However, with the implementation of the re-designed lab activities, the instructor became very involved in the lab component of the course, spending a great amount of time in the lab facilitating students' engagement in the inquiry activities. The instructor also initially took on the responsibility of grading students' inquiry reports because she wanted to monitor how students were adjusting to her new teaching approach. As the semester progressed however, the instructor began to limit her presence in the lab, and handed over grading responsibilities to the TA. Thus, by the end of the semester, the TA had assumed more responsibility for organizing and facilitating the lab activities.

Students' roles. Inquiry-based learning environments require students to be active participants in their learning, sometimes collaborating with others to complete authentic tasks. Students were required to be active participants to complete the inquiry tasks in this course, however they were given the option of working individually or in groups. Most students chose to work collaboratively to complete inquiry tasks, although there were two students who consistently worked alone, interacting very little with the other students.

Technological affordances. As computers have become absolutely integral in most forms of scientific practice, the science education community has come to view computer technologies as offering essential opportunities for supporting inquiry-based learning (Edelson, Gordin, & Pea, 1999). Digital libraries, which can provide instructors and their students with access to the same data and tools commonly used by scientists, are an especially promising new technology that presents unique opportunities for learning in inquiry-based learning environments.

Students had access to the Digital Library for Earth Systems Education (DLESE – available at: http://www.dlese.org) in the laboratory, and were encouraged, but not required, to use it while completing their inquiry assignments. The DLESE library currently houses over 9,000 resources, about 45% of which are in the 19 thematic collections related to a range of topics dealing with geological science. Its features include the ability to search for resources according to: educational level (including the first two years of undergraduate geosciences, the last two years of undergraduate school, and graduate level resources); resource type (e.g., lesson plans, visualization data, animations, and video); collections (DLESE resources that are organized by themes or other evaluative criteria, e.g., DLESE Reviewed Collection); and standards (including the National Science Education Standards and the National Geography Standards). Once a resource of interest is found, a summary of the resource's properties is displayed including: a brief description of the resource; resource type; subject areas addressed; and the educational level for which the resource is appropriate. Users are also able to see reviews of the resource by other teachers and students, teaching tips for using the resource in a class, and other resources related to the topic of interest.

Assessment strategies. In line with inquiry-based pedagogical approaches, multiple assessment strategies were used in this course, including lab reports, individual projects, project presentations and inquiry-based exams. The following represents the type of questions students encountered on their inquiry-based exams:

> *You – a noted paleontologist/geologist –have been helicoptered into Dante's Island, a remote island in the Hagen-Das Ocean. You have drawn a map of the island, collected samples from the island (samples 1-10) and have constructed lithologic columns for each locality. Your task is to reconstruct the history and paleoenvironments of Dante's Island. Don't forget to include sediment analysis (if applicable), the rock name (if applicable – don't forget the major rock types and the specific rock name) , the fossil name (if applicable, as scientific as possible) the interpretation of lithologic columns, and resultant geological report: the historical reconstruction of Dante's Island.*

This type of assessment item is well aligned with the objectives of the course as well as its pedagogical design. It presented a relatively authentic problem that students can not solve with a memorized concept. Instead, the question requires the application of scientific inquiry skills. Students should do well on such an exam given that they have had ample opportunities to develop and practice inquiry skills throughout the semester.

Findings and Discussion

Successes and Challenges in Integrating Inquiry-based Learning

The primary researcher formally interviewed the instructor three times throughout the semester about her perceptions of (a) the course, (b) students' reactions to the course, and (c) students' performance. Overwhelmingly, the instructor was pleased with the changes to the course and students performance in the course. Based on the instructor's responses, the successes and challenges in aligning the critical dimensions of an inquiry-based learning environment are discussed below.

Objectives.

The objectives for this course were to help students (a) develop skills necessary to participate in scientific inquiry processes related to geological inquiry, and (b) develop deep understanding of the relevant geology content. Overall, the instructor reported being very pleased with students' performance in the lab while completing their inquiry assignments. From the beginning of the semester, the instructor observed students actively engaged in questioning and discussing:

> …*These students are interacting more, they're asking more questions, they're questioning what their knowledge base is, they're questioning on how they should find the knowledge, they are staying in the lab until 3 o'clock which is unheard of, usually they leave a lot earlier, they don't think its that important, they're not just filling in the blanks like they were last year -they're actually discussing what they are looking at*…

This trend continued throughout the semester, and by the end of the course, based on her observations the instructor felt that students demonstrated improvement in the important scientific skill of asking scientific questions:

> *…And by my observations of the class, they got much better at asking questions. And being able to then figure out how to ask, not only ask the question, not being afraid to ask the question about an unknown situation, but how they might go about collecting the data, and then how to finish the project. And that was really exciting to me.*

Content.

Like many other college and university instructors, it was difficult for this instructor to reconcile the desire to teach a large amount of content with the desire to engage students in authentic inquiry activities. In order to deliver this course using an inquiry-based approach, the instructor had to sacrifice time devoted to covering specific content. Thus, it was a challenge for the instructor to change her teaching methods, because utilizing an inquiry-based approach meant sacrificing content coverage for depth of understanding and investigation. However, from the instructor's observations of students' interactions in class, and their performance on the final exam, the instructor reported feeling strongly that the inquiry-based approach is effective and worthwhile:

> *I think I've really come around myself to think that the best thing they could possibly take away from the course is, at least a way of approaching problems. That, you know, how to ask questions, make hypotheses, how to test it, and collect the data and write about it and make it make sense. And they know probably a little bit about invertebrate paleontology and the utility of using these organisms for particular questions, and I think they got that. They might not be able to go into say 'oh that's a Strophomena brachiopod, a year from now, but they'll know what book to go, or what, how to, you know where to get the information, okay. But, so basically I think I've backpeddled a little, not backpeddled, but I think the process of learning science was more important than the product. Like 'This is a Strophomena brachiopod - don't forget!' But why is it a Strophomena?, and how do we know it is?, and where can you get that information if you forget down the line that it is?, and what are they useful for? Telling time? Environments? And so I think they got the big aspects…*

Pedagogical Design.

As noted above, this instructor was already open to inquiry-based learning strategies, but she had not previously incorporated these strategies into this level of course in a comprehensive manner. Through the collaborative re-design process, the instructor reported learning a great deal about how to structure her lab activities to promote student engagement in inquiry. The instructor began to recognize the importance of providing students with a major scientific question to investigate for the duration of the lab:

> *…You and I spent the summer rewriting my labs to be, with the major question. I've never done that before, I just, you know, when we looked at my old labs in a new light I go 'oh my god! I'm like really misleading them! I should put the question first!' And you were the one who mentioned that. So, I go to the back of the lab and I put the question from the back to the first. And here's your main goal, and here's the steps to get there. And that's working really well – really well, so I like that.*

The use of one major scientific question to guide students' inquiry activities proved very successful for both the instructor and the students:

> *…I think they [the students] see a purpose, I think because of the inquiry-based way we rewrote them they see a purpose for it [the lab activities]. They see an applied reason for doing it. And I think that also a question that they know if they collect a certain amount of data they can get an answer for. And I think that makes it interesting for them. So I feel really good about it – it's worth all the effort I think.*

Through the redesign and implementation experience, the instructor was able to develop her skills in designing and implementing inquiry-based activities. She felt confident enough after her experience with this geology class, to begin re-designing the lab activities for a Paleoecology course she was teaching the following semester.

Tasks.

With regards to the inquiry tasks, the instructor reported noticing a lot of hesitancy on the part of students to begin engaging in the inquiry activities when presented with the first inquiry task. However, by the time students had to begin the second inquiry task, they had gotten over their fear of the unknown, and were ready to quickly jump in:

> *And then once they got started, it was really a lot of hesitancy at first, but then they started getting it. And they said 'oh I see what's going on.' And it took them a while the first lab to get, to understand what was going on. But this lab, oh my goodness, they started it right away! I mean, there was not like, 'huh', there wasn't that jaw opening and those big wide eyes that had nothing, you know, communicated to me they were just clueless, what I said to them didn't register. But this lab [2nd] registered. So they were already just popping along. Yeah, I was impressed.*

It should not be surprising that students initially show resistance to inquiry-based learning approaches given that relatively few undergraduate science courses expose them to this pedagogical strategy. However, given the opportunity to engage in inquiry, it seems likely that students will quickly adapt and get engaged in the activities.

Instructor Roles.

For the instructor, utilizing an inquiry-based teaching approach required much more work and time. The instructor was required to engage in more hands-on work in the lab, facilitating student learning. In addition, the instructor reported spending a large amount of time grading a number of the inquiry assignments. However, despite the additional amount of work and time required for teaching using the inquiry approach, the instructor reported that it was an enjoyable experience all around:

> *It was a lot of work. It was a lot of work. It was a lot of hands on work...Umm, its harder to grade them[the lab activities] because they could have a range of answers, there's not fill in the blank, so it takes a lot more time. And if the TA doesn't understand that there is alternatives, that raises a lot of grade issues... Whereas if you have a person, whose more familiar with the information and thinking in that way, you know 'if they collect this data they could have this answer, if they collected this data they could have that answer' um, then it's a lot easier. So it was a tremendous amount of work for me because I had to grade a lot of the labs, and but, I enjoyed it I have to say.*

Because the instructor took a more hands-on role in the lab, the TA's role was initially quite ill-defined. This was partially because the instructor was curious as to how her new teaching approach was working with the students, and partially because the TA had very little experience facilitating student engagement in inquiry activities. However, as the semester progressed, and the TA became more comfortable with the inquiry approach, he took on a more active role in the lab. The TA describes his perception of how his role in the course evolved into a situation with which he was both familiar with and comfortable:

> *…At the beginning it was basically, set up, take down, and answer questions when we're in lab. And now its become more what I, closer to what I am used to as far as here's the lab, set it up, handle questions, grade it and have the grades to me. That's more, that's closer to what I'm used to. At least that way it gives me a better, it gives me more feedback as far as where they are going because I'm actually the one seeing the labs now. And also, I think that, so as far as my role, I'm definitely taking a more active role in it and that's definitely better. I also, yeah, so I think that's the main thing, my role has become much more active as far as, as far as the whole lab process goes.*

Student Roles.

Turning to the ways that students adjusted to their new roles in an inquiry-based science course, the instructor noticed that initially students were still relying on their old schemas of teacher-student interaction. The instructor remarked the following:

> *I see them fishing for answers - 'Well, what is the name of this rock?' You know, just take me off guard right. And I said 'Oh, well you're supposed to figure that out' But they're still trying to operate on the old systems of give me the answer. And I'm trying hard not to do it like that.*

Thus, it is not only difficult for students to adjust the challenge of engaging in inquiry tasks, but also to a different system of teacher-student interaction. They were used to a relationship wherein the instructor was viewed as a primary source of knowledge and so they expected to continue that relationship once they ran up against a complex problem. However, the instructor's approach to addressing this issue was to remind students that they were engaged in learning the process of science, and to offer positive reinforcement saying things such as: *"You're right on!…We're trying to get you to be geologists here."*

Although a full report of student engagement in the inquiry-based learning tasks is beyond the scope of this paper, observations of student behavior in the laboratory as well as interviews with the students indicated that some students were much more successful than others in making the transition from their normal role as passive learners in science courses that are traditionally focused teacher talk (e.g., lectures), readings (e.g., textbook), and tests (e.g., multiple choice exams). Helping students move from passivity to activity remains a major challenge for any geosciences instructor wishing to foster inquiry-based learning, although as noted above, this may change if science education reform efforts are ultimately successful at the K-12 level.

Technological Affordances.

The dimension that was most misaligned with the inquiry-based learning approach was the technological affordances provided by DLESE. Despite the proclaimed potential of digital libraries to transform education (Marchionini & Maurer, 1995), the students in this course were unable to make effective use of the technological support provided to them, even though DLESE was expressly designed to support teaching and learning in the geosciences. In fact, the instructor rarely saw students making use of the computer to help them complete their inquiry assignments, and when she did, they did not make use of DLESE, but preferred to utilize search engines such as Google with which they were already comfortable.

> *But, I didn't see them using the Internet that much in the … class, and that might be because I didn't have a specific question for them to go and say 'go look on the Internet'… unless I really have a specific question and tell them to go use the Internet, I think they tend not to - at least at this point.*

Observations of the students in the laboratory as well as interviews with them indicated that they perceived a lack of utility in the DLESE resources for the inquiry activities in which they were engaged. This negative reaction may have partially stemmed from the lack of specificity in the search terms associated with DLESE resources and the rather unique nature of the content in this particular course. Alternatively, DLESE may simply not contain resources relevant to the subject matter of this course. It also is plausible that some of the students lacked the self-regulated learning skills to conduct effective searches (Rogers & Swan, 2004). In any case, aligning the features of digital libraries with inquiry-based learning remains an important challenge.

Assessment Strategies.

For the instructor, one of the best outcomes of utilizing inquiry-based teaching approaches was demonstrated in students' performances on the midterm and final exams. After the midterm exam, the instructor stated:

> *We've solved the major problem which I've had in the past which is when I gave the exams, I had inquiry-based exams but I hadn't really got them to do inquiry-based works in a really organized manner. And this time I had 4 A's on this midterm exam. That's the biggest amount of A's I've ever had. I usually get 1 or 2 A's since I've been doing this on the semester system - so plus or minus 4 or 5 years. And so they did really, really well.*

Thus, by the midpoint of the semester the instructor was already seeing benefits to this new approach to teaching. This improved student performance continued throughout the rest of the semester, with the students in this inquiry-based geology class outperforming the instructors previous students on the final exam.

> *I was really impressed with the quality of the exams on the most part… Most of the grades were really good. Much higher than I, than I thought...So I'd say, compared to last year, the distribution of grades is really high…*

Lessons Learned and Future Directions

> *Proper planning for inquiry-based learning is labor intensive for the course instructor, teaching assistants, and even the students. A great deal of effort must go into preparing experimental materials, critiquing protocols, supervising students, and mentoring teaching assistants to be good scientific inquiry coaches.*
>
> *(McIntosh, 2001, p. 3)*

The amount of work that went into designing and implementing the inquiry-based learning activities used in this geology course was well above the norm. For the instructor, adopting an inquiry-based teaching approach required a significant shift from her traditional role in the course. She spent much more time in the lab interacting and guiding student learning, a role that was typically handled primarily by the course TA. Her increased presence in the lab partially stemmed from the fact that the course TA was inexperienced with facilitating inquiry-based learning, thus the instructor had to spend time mentoring the TA through the process as well.

Nevertheless, the instructor's comments clearly indicated that the benefits of using inquiry-based learning methods with students outweighed the extra costs in time and effort. With the proper alignment of course objectives, content, pedagogical design, tasks, assessment strategies and instructor and student roles, an inquiry-based learning environment was designed and implemented in which students were able to successfully develop skills in scientific inquiry as well as geological content knowledge.

Students also responded favorably to the format of the course and labs. Students' reactions to the labs were overwhelmingly favorable. At the end of the course students rated their knowledge for the major topics covered in lab as being higher than before the course. And overwhelmingly, they were able to participate in authentic scientific inquiry activities with higher levels of engagement than they exhibited in traditional courses.

The one major concern students expressed was with the lack of support they felt while engaging in inquiry activities, especially with respect to their interactions with the TA. At the beginning of the semester students reported feelings of being lost and feelings of frustration. However, later in the course, they adjusted to their new more self-reliant roles and obviously engaged in authentic inquiry.

A number of lessons related to teaching a geoscience course using inquiry-based methods can be drawn from this experience. The first deals with the misalignment of the technological affordances dimension. The rationale for deciding to incorporate a digital library into classroom use needs to be considered carefully, because like many technological innovations we must consider not only the potential benefits the technology can bring, but also how the learning tasks must be changed in order to take advantage of such benefits (Hoadley & Bell, 1996). As the instructor noted above, geoscience instructors wishing to incorporate use of a digital library into their course may need to design the learning tasks in such a way that it requires use of the digital library for completion of the task. In this particular geology class, although DLESE was suggested as a resource to be used for completion of almost all lab activities, it was only required for the completion of Lab Activity 2. It was hoped that the mandatory use of DLESE early in the course would give students exposure to the digital library, and encourage future use. Unfortunately, this was not the case. It may be that students are accustomed to using their textbook or asking another individual when faced with needing additional information or clarification of concepts or ideas. Students may be hesitant to put in the additional time necessary to explore web-based resources found in a digital library. Unfortunately, for many students inquiry in the classroom is still considered school-work, and thus students may be more concerned with completing the work than investing time to explore ideas and improve their work (Krajcik, et al., 1998). More research is needed to explore the reasons why students chose not to make use of the technology afforded to them in this particular class. Such research should be designed to provide insight into what resources students require and prefer to use to support their learning in inquiry-based environments.

The second issue relates to the instructor role in the course. The importance of having an instructor who is comfortable and skilled in facilitating and guiding inquiry is clear. Without appropriate instructor guidance and facilitation, students may become frustrated because they are unable to reach understanding of the scientific concepts on their own

(Clough, 2002). Some level of discomfort is inevitable and perhaps even desirable when transitioning from one dramatically different pedagogy to another. These students experienced some frustration at the beginning of the course while engaged in inquiry, which they attributed to the lack of guidance they were receiving. Based on classroom observations as well as discussions with both the instructor and TA, some of this frustration may have been avoided if the TA had been more experienced with inquiry-based learning approaches. This is an important factor that needs to be given due attention when one considers implementing an inquiry-based learning environment. Instructors must learn to walk a fine line between providing too much support and thus maintaining the teacher-centered nature of traditional science courses at the undergraduate level, and too little support that would leave students floundering without sufficient scaffolding. Instructors can begin to do this by introducing their students to new ideas or tools when and where necessary, but also by listening and diagnosing the ways that their students are interpreting the instructional activities (Driver, Asoko, Leach, Mortimer, & Scott, 1994).

Final Words

With the increased use of inquiry methods in K-12 science education, it is of utmost importance that college science instructors begin utilizing these methods. The research base for enhanced teaching, learning, and assessment in undergraduate science education is considerable (Bransford, Brown, & Cocking, 2000) but the extent to which it has been put into practice is still limited (National Research Council, 2003). This paper provides a framework examining the alignment of the critical pedagogical dimensions that can be used to help instructors develop, implement, evaluate, and improve inquiry-based science courses. One example of an inquiry-based undergraduate geology laboratory experience that successfully aligned most of these dimensions was also illustrated.

More research and development is strongly recommended, but instructors should be encouraged to take the plunge into inquiry-based instruction. Instructors who take this initiative should expect some resistance from students, peers, and even administrators. There is always some risk involved in change. But nothing ventured, nothing gained.

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CHAPTER 6

EPILOGUE

The challenge is large, significant, and achievable. It also is too much to place on the shoulders of any one group. Achieving the high standards outlined for science education requires the combined and continued support of all…

(National Research Council, 1996, p. 245)

The purpose of this epilogue is to reflect on my experiences conducting my research and writing this dissertation. I will also present my final thoughts on the results of the study.

Conducting the Research

Finding a research site and collaborator

Conducting research begins well in advance of actually collecting the data; it begins when you start planning and designing the research study. Although I knew fairly early on what I was interested in researching, finding a research site was a much more complicated issue. With my graduate assistantship focused on the evaluation of DLESE (the Digital Library for Earth Systems Education), it only made sense to incorporate DLESE into my dissertation research. This was also strongly encouraged by my doctoral committee chair, Professor Thomas C. Reeves, who wrote the proposal that funded my graduate assistantship.

With these opportunities before me, I knew that my research would involve working with someone teaching undergraduates in a geology or geography department. Professor Reeves and I decided that the best approach would be to do a presentation for the geology and geography departments at The University of Georgia, to introduce them to DLESE, and gauge their interest in participating in an on-going research project that would be kicked off by my dissertation study. Although we contacted both departments in late November of 2003, we were unable to schedule meetings with each department until late March of 2004. Needless to say, this significantly hindered my progress in completing my prospectus.

Nonetheless, the presentations Dr. Reeves and I gave to both the geology and geography departments were a success, and surprisingly I quickly had not just one but three professors interested in working with me! At the time, my primary interest lay in working with an instructor of a large-lecture section of the introductory geology course, to re-design the course to make it more interactive and engaging for students, with the support of technology (e.g., online discussion or use of interactive web resources). Two of the interested professors were instructors of the introductory level geology course, which is where my primary interest lay. The third professor was an instructor for an upper-level small geology course.

Initially, I was very eager to work with the two professors who were teaching the introductory geology course, but after a few meetings with all three professors, it became clear to me that that might not be the best option. As already alluded to in my prologue, I was very cognizant of the amount of time and effort that both I and the instructor would need to invest in order to make substantial enough changes to the course in order to see any impact on student learning. Of the three instructors interested in working with me, it was Dr. Sanders (not her real name), the instructor for the upper-level geology course, that ultimately was most willing and able to commit to substantial changes in her pedagogy, and able to invest the time and energy that would be required. Thus, although I had to adjust my research focus from a large introductory class to a small advanced one, in order to work with

Dr. Sanders, ultimately this proved to be the best decision, and probably one of the reasons that this dissertation research was successful.

Collecting the data

In yet another surprising turn of events, I ended up doing a purely qualitative study. With my background in psychology at the University of Alberta, I had much more experience conducting quantitative rather than qualitative research. However, my research questions dictated the choice of research methods, and a qualitative approach was the only one that made sense for this study. Through this experience, I have been able to expand my research horizon and become much more skilled in using qualitative methods such as interviewing and participant observation. Below, I discuss some of my reactions to some of the aspects of the data collection procedures I engaged in for this research study.

Classroom Observations.

I had proposed to collect data for the entire duration of the course in Fall 2004. This turned out to be quite the intense experience. I went to *every* lecture and *every* lab period. I tried to take copious notes of what the professor was saying, what students said, and what students did. This was not only challenging in the sense that it is often difficult to keep up with conversations, but I had the added challenge of trying to 'decipher' an unfamiliar language: the language of geologists! Often, Dr. Sanders and the students would use precise scientific terms with which I was unfamiliar. If it was a word that I was unfamiliar with and it was not on Dr. Sanders' PowerPoint slide, I would sound it out phonetically, and look it up in the geology text after class. Thus, there was a very steep learning curve for me, in becoming familiar with the discourse of the geology classroom. However, as the semester progressed, I developed a greater understanding of the subject matter, and thus was able to keep up. In the end, I truly felt like I was learning the subject matter along with the students.

Interviews.

I conducted interviews with all participants (7 students, instructor and teaching assistant) at three points throughout the semester. With each interview lasting anywhere from 20 minutes to 90 minutes, this turned out to be quite an investment of time and energy. However, these interviews proved to be such a rich source of information, and provided valuable insight into both students' and instructors' perspectives on the class. I felt very fortunate that I was able to develop a good rapport with the students (and instructors), and thus they were very frank and honest with me in their interviews about discussing their reactions to and perceptions of the course.

Archival Data

I collected so much archival data that it almost became overwhelming! But again, the process of looking back at students' work samples, and comparing those to what I observed in the classroom and to what students discussed with me in their interviews, provided great insight into how students were constructing knowledge in this inquiry-based learning environment.

Managing the Data

Organization is not one of my strong suits. In fact, it took me until November before I finally found a binder large enough for all the students' work samples! If there is one recommendation I have for other students it is to develop an organizational system early on.

Writing the Dissertation

Data Analysis

Qualitative research tends to include the collection of massive amounts of data, which then needs to be analyzed. Fortunately, I felt like all the data I collected was relevant and applicable to my research questions, so the collection of unnecessary data was not an issue for me. Rather the issue for me was getting my data into a form from which I could then analyze it. If I can be frank, transcribing the interview data and expanding my observation field notes was a extremely time consuming activity. Often it was a painful and tedious process, but it was a process that I did myself (rather than hiring someone else to do) because I know the first step in data analysis occurs when you transcribe your data. Nevertheless, I hope to limit my involvement in this aspect of the qualitative research process in the future!

However, once it actually got to the point where I could analyze my data, I found this to be a very rewarding and fulfilling experience. Going through and coding all the interview transcripts, observation field-notes, and student work samples and finding interesting results, is what research is all about for me. Although it was a time-consuming process, the results were worth the efforts.

Journal-ready Manuscripts vs. Traditional Format

As I've expressed to many of my colleagues both prior to writing the dissertation and during the process, I have my reservations about the journal-ready manuscript dissertation format that has recently been encouraged within the Instructional Technology doctoral program at the University of Georgia. Despite the benefits of using the manuscript format as opposed to the traditional format (e.g., four ready to submit articles in hand), there are significant challenges that must be overcome in order for this format to be successful. It became apparent to me while writing my prospectus that the manuscript format was going to require *much* more work in the end. With the traditional format, prior to data collection you have the majority of the dissertation complete (i.e., the introduction, literature review and methodology chapters). However, with the article format, the bulk of the work awaits you following data collection. For each article you need to write a relevant, but abbreviated, literature review, a methodology section, results, and discussions and conclusions. There is also the additional challenge of making these articles complete enough that they stand on their own without readers having to refer to other parts of the dissertation, but at the same time having a sense of coherence between the articles so that they do make one complete dissertation.

I think there is something to be said for going through the process of writing the traditional dissertation. I think by having to do an extensive literature review, and methodology chapter, you are given the opportunity to think in depth about the issues that may arise in your research. In addition, I think that the traditional format gives an individual a greater amount of time 'absorb' and reflect on what your data truly means. Writing 3 or 4 separate journal articles requires different skills, and thinking ability, than does writing the traditional dissertation. Writing a journal-ready manuscript requires you to fully grasp the meaning and implications of all your data, and then to reframe these findings into a format appropriate for submission to a journal. I almost feel as though, when you sign up to complete the manuscript format dissertation, you are required to go through the thought process necessary to complete a traditional dissertation, in addition to then transforming that information into journal-ready manuscripts. I know that for myself, this was a very difficult process, particularly because I had so many interesting results, that it was very difficult to limit what to report.

The Actual Writing Process

I honestly have to say that this has been one of the most intense academic experiences of my life. I was fairly confident throughout the process that I would finish this dissertation on time (perhaps too confident!) but getting there was definitely a struggle at times. Knowing what kind of writer you are (i.e., the conditions under which you write best such as the time of day) is vital. I learned quickly that I am a writer that needs a large block of time to sit down and write. Thus, finding large blocks of time to write was sometimes difficult. In addition, I quickly learned that sometimes my bed is not the best place to try writing (although sometimes I had brilliant thoughts there!). Thus, I adopted one of the local coffee shops in town and made it my home. By only *working* while at the coffee shop, I soon developed an association between writing and the coffee shop (those behaviorists were onto something!) and thus I spent many a productive night typing away.

Revisions, revisions, revisions are the key to any good piece of writing. I am forever grateful for all the feedback I received on drafts of these manuscripts from Dr. Reeves. When it came down to 'crunch' time, Dr. Reeves was able to provide me with critical feedback on my manuscripts, making them much, much better than they would have been without his feedback! In addition, the discussion and feedback I have engaged in and received from all my committee members has been invaluable. The beauty of having such a diverse committee is that they each member brings with them different perspectives and ideas. Having the opportunity to engage in conversations about the ideas contained in this dissertation with each of my committee members has been a remarkable experience, and has had a profound and lasting impact on my thinking.

The Results

What have I learned about integrating inquiry-based learning and a digital library into an undergraduate geology course? The short answer would be – I've learned a ton! Inquiry-based learning can be used in an undergraduate geology course, albeit with a lot of time and effort. The role of the instructor in facilitating the transition from traditional didactic learning to inquiry-based learning is crucial. However, students in this study demonstrated that even *without* optimal levels of support, they are able to successfully appropriate and engage in inquiry practices. With respect to the digital library, integration was not as seamless as I had hoped. Students, rarely, if ever, made use of the library, thus the great promise for a digital library to support student learning in an inquiry-based environment was never realized. However, the results from this study can provide both instructors of inquiry-based science courses, and developers of digital libraries with valuable insight and guidance for the future.

Next Steps

So what's the next step? Well, after this experience I am happy to say that I still love research! I intend that the ideas contained in this dissertation will be the beginning of a long line of research projects, keeping me busy and engaged for many years to come. As a next career step, I am interested in pursuing one of two paths. The first path would be to continue my work on examining ways to improve educational practices (particularly in the sciences), with or without technology. I am very interested in pursuing research that examines design issues as it relates to creating effective learning environments at all levels of education. Alternatively, I would take great pleasure in working with higher education faculty designing and implementing innovative pedagogies. Facilitating faculty development of innovative teaching practices is a process that I find personally and professionally rewarding.

Ultimately, I envision working in a collaborative, interdisciplinary work environment, where I can continue to be involved in innovative research projects. Ideally, this environment would be one in which there is a shared vision and a strong desire to have research influence, and be influenced by teaching and learning practices.

References

National Research Council. (1996). *National science education standards.* Washington, DC: National Academy Press.

Appendices

Appendix A

DLESE Resource Statistics

Table A1

Number of resources by subject

Subject	Number of Resources
General Science	7942
Geographical Sciences	2291
Geological Sciences	6391
Oceanographical Sciences	4860

Table A2

Number of resources by grade level

Grade level	Number of resources
Primary (K-2)	888
Intermediate (3-5)	1740
Middle (6-8)	3344
High (9-12)	4109
College (13-14)	5164
College (15-16)	4144
Graduate/ Professional	4029
Informal	336
General public	1563

Table A3

Number of resources by resource type

Resource type	Number of resources
For the classroom (e.g. lesson plans, instructor guides, classroom activities, computer activities, etc.)	5504
Visual (e.g. illustration, photograph, map, video, etc.)	6183
Text (e.g. glossary, report, book text, etc.)	4157
Audio (e.g. sound, lecture, webcast, etc.)	311
Portal (e.g. government, non-profit, educational, commercial)	587
Services (e.g. clearinghouse, ask an expert, etc.)	546
Dataset (e.g. in-situ, remotely sensed, modeled)	645
Tools (e.g. software, calculation/conversion tool, code)	311

Appendix B

Sample Inquiry-based Task

Lab 2: Biogenicity and Earth's Earliest Life
(subtitled, "*Earth's Earliest Life and Biogenicity Debate*")

Note, a biogenicity critique of the paper you read (either Schopf or Brasier's) will be due with this lab write up on Tuesday, Sept. 14, 2004

This lab shall be typed (data can be in pencil, sketches can be in pencil and attached to the lab) and due on Tuesday, Sept. 2004.

One of the most pressing questions in paleobiology and astrobiology today concerns the criteria by which we recognize life on earth. Can criteria for life on Earth be directly used to recognize life on other planets? In this lab you will be using a variety of sources to help with this pressing question: fossils, micrographs (high-resolution photographs), thin sections, *Nature* and *Science* readings, and the web site DLESE (or additional web information, such as the Georgia Library's Galileo database or NASA).

The main questions that you will be tackling in this lab today are:

1) Develop biogenicity criteria for recognizing life forms in ancient Archean Eon rocks. What types of information would you be looking for, and how would you analyze it?

2) Can the criteria you develop for Archaen rocks be used to recognize life on other planets?

You have a series of workstations that are set up to help you with the questions listed above.
YOU NEED TO DO THE WORK STATIONS IN CONSECUTIVE ORDER!

I. Work Station No. 1. First, discuss in your groups (or individually!) the biological criteria for life that you are most familiar with from your background and make a list of these criteria. Second, check your list with DLESE and/or google criteria for ancient life on earth and compare that information to yours. Type up your information in tabular format. Lastly, determine which of the criteria you would use for the rest of this lab. You would use the criteria as a "working hypothesis" and you need to stick with this hypothesis throughout the lab. If you find this in untenable, then keep track of your criteria changes, and jot down why you made the changes to the criteria you are using for this lab.

II. Work Station No. 2. The thin sections at this workstation may have living and non-living matter in them.

A. Using the criteria you developed in Work Station No. 1, can you determine which slides (B-7, B-10, & 29-49) are life forms, or just sediments? Sketch each sample using a representative from each of the slides. Be sure to include magnification and scale if applicable. Please give your evidence and justification for your interpretation.

B. Examine the histological-tissue thin sections (labeled 2a, 2b, 2c) and determine if they fit your criteria for what a life form is. Next, for each thin section, determine if the life forms (if they *are indeed* life forms) are prokaryotic or eukaryotic and give evidence for your reasoning.

III. Work Station No. 3: Please examine the polished hand specimens. These rocks are what geologists would commonly see in the field if they studied the Archaean Eon system. One of the most difficult challenges is to determine if these rocks may hold biogenic information. Thus, of the rocks in this workstation, which ones may be biogenic? Give evidence for your reasoning. Are there any rocks here that you can name specifically? Finally, what additional information or technique would you use to clearly establish whether these rocks contained early life forms?

IV. Work Station No. 4: At this station, you have both polished hand specimens and petrographic thin sections that have come directly from these hand specimens. Please examine both the hand specimens and thin sections carefully.

A. Determine what type of information you can retrieve from the hand specimen in relation to the question of biogenicity.

B. What type of geologic information do the petrographic thin sections give you?

C. Can you now attempt to answer the two questions posed at the beginning of this lab? Explain your reasoning/hypotheses.

V. Work Station No. 5: You have found these specimens under a snow bank in Glacier National Park. These rocks were *in situ*, and you used your rock hammer (sledge hammer!) to get them out of the outcrop, and you polished some of these hand specimens so you could see the interior of the rock without weathering obscuring your view.

A. What is your interpretation of these rocks? Explain and justify evidence.

B. If these rocks are 1.2 billion years old, can you determine the climate that these ancient rocks may have represented? (i.e., arctic conditions, temperate conditions, subtropical conditions, tropical conditions). Explain your answer.

C. What does the color of the rock tell you about the atmosphere 1.2 billion years ago? Explain and give evidence.

VI. Work Station No. 6: Schopf versus Brasier Biogenicty Debate Concerning the Oldest Body Fossils on Earth, the 3.5 Billion-Year-Old Apex Chert Microfossils. You will debate the controversy over recognizing the earliest of Earth's life forms. At the end of the lab today, we will debate the issues starting at 230 PM (or earlier if you want). Please write up a short critique (critical review of the paper) based on the paper that you read for the debate. Consider these topics when writing your critique: 1) do the authors try to refute their hypothesis, or do they try to support it? 2) What questions and methods do the authors use to answer the question of biogenicity? 3) What do their results indicate? 4) Are their conclusions valid? Or, are they missing some information that they should have included? Explain and/or justify your statements. This critique will be typed, double-spaced (with 1.5 inch margins), and up to four pages, with 1 inch margins. Turn in the critique with this lab next Tuesday, Sept. 14.

NOTES:

Appendix C

Midterm and Final Exams

EXAM 1

GEOL XXXX, FALL 2004

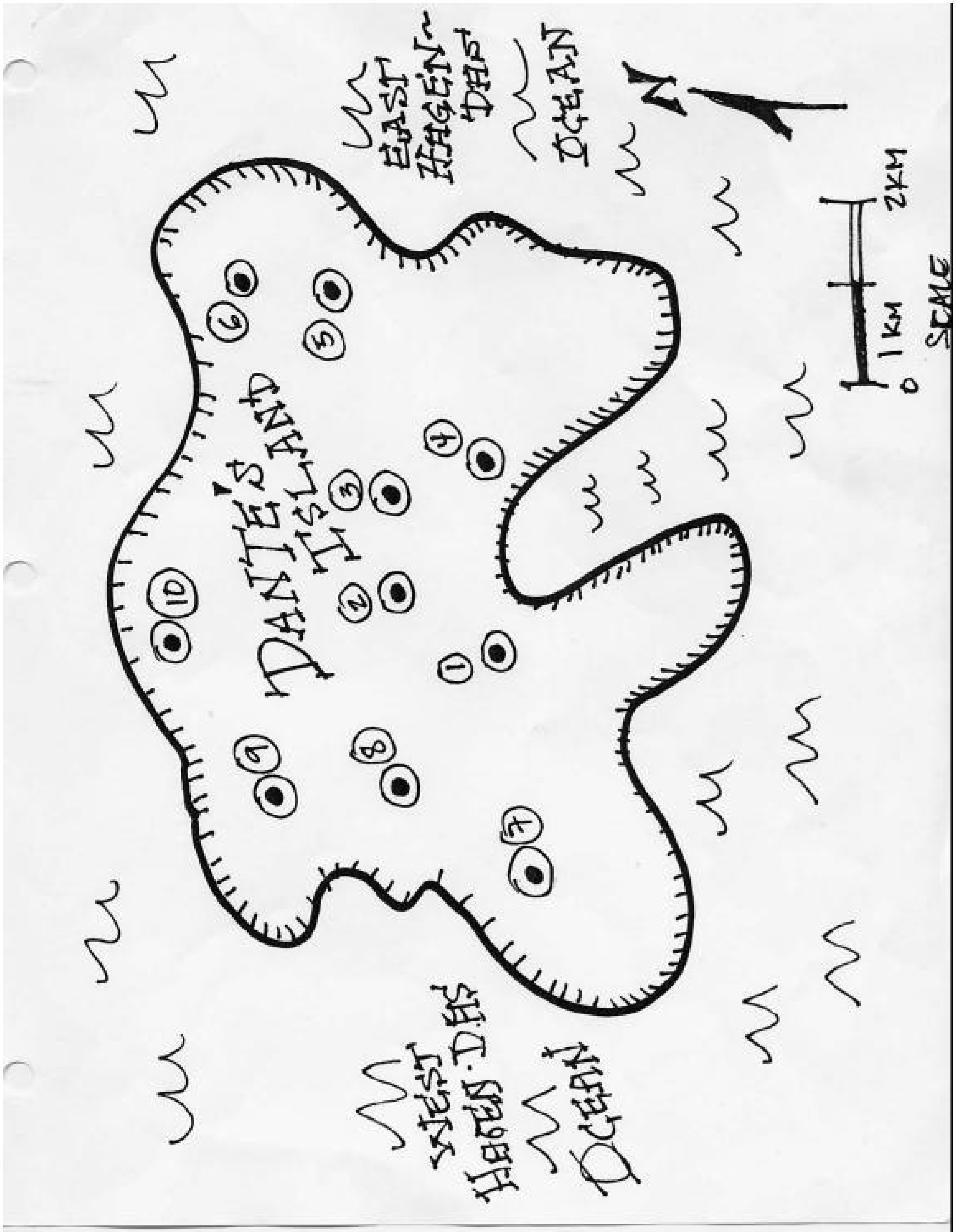
NAME:

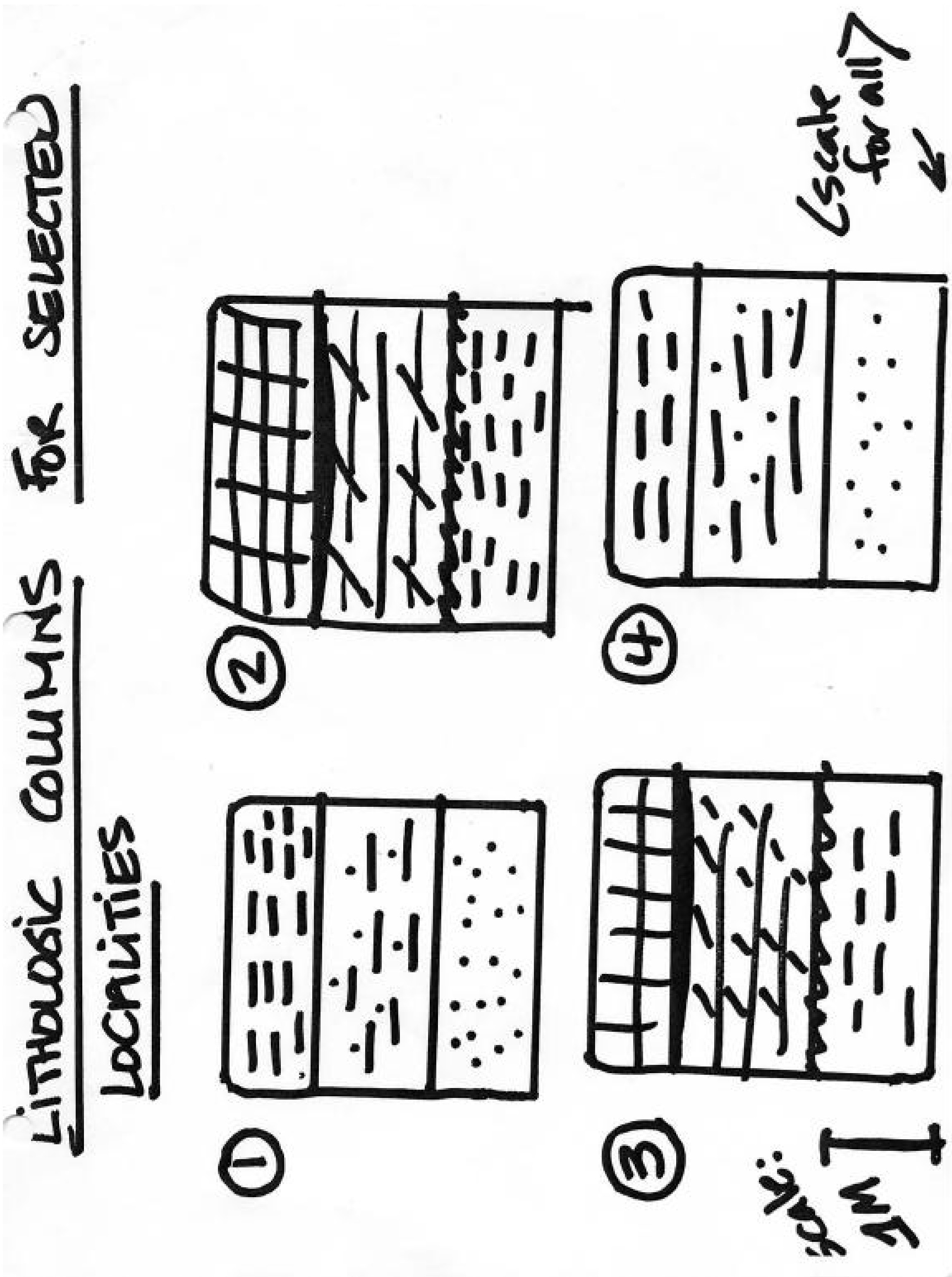
POINTS POSSIBLE: approx 130 **POINTS EARNED: ____________**

I. You – a noted paleontologist/geologist – have been helicoptered into Dante's Island, a remote island in the Hagen-Das Ocean. You have drawn a map of the island, collected samples from the island (samples 1-10) and have constructed lithologic columns for each locality. Your task is to reconstruct the history and paleoenvironments of Dante's Island. Don't forget to include sediment analysis (if applicable, 2 pts each), the rock name (if applicable – don't forget the major rock types and the specific rock name, 2 pts each), the fossil name (if applicable, as scientific as possible, 4 pts each variable), the interpretation of the lithologica columns (3 pts each), and resultant geological report (20 pts): the historical reconstruction of Dante's Island.

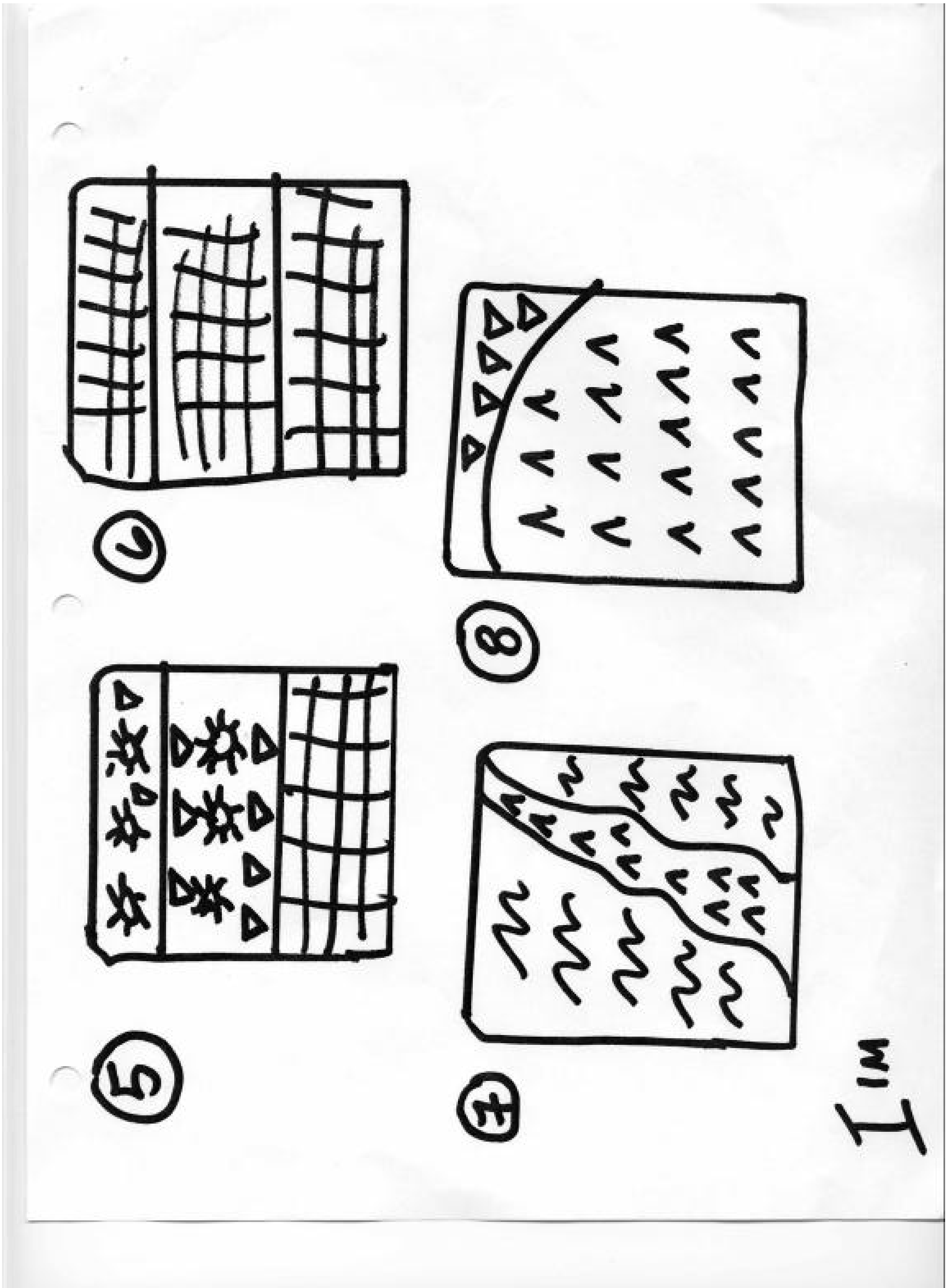
*Attached:

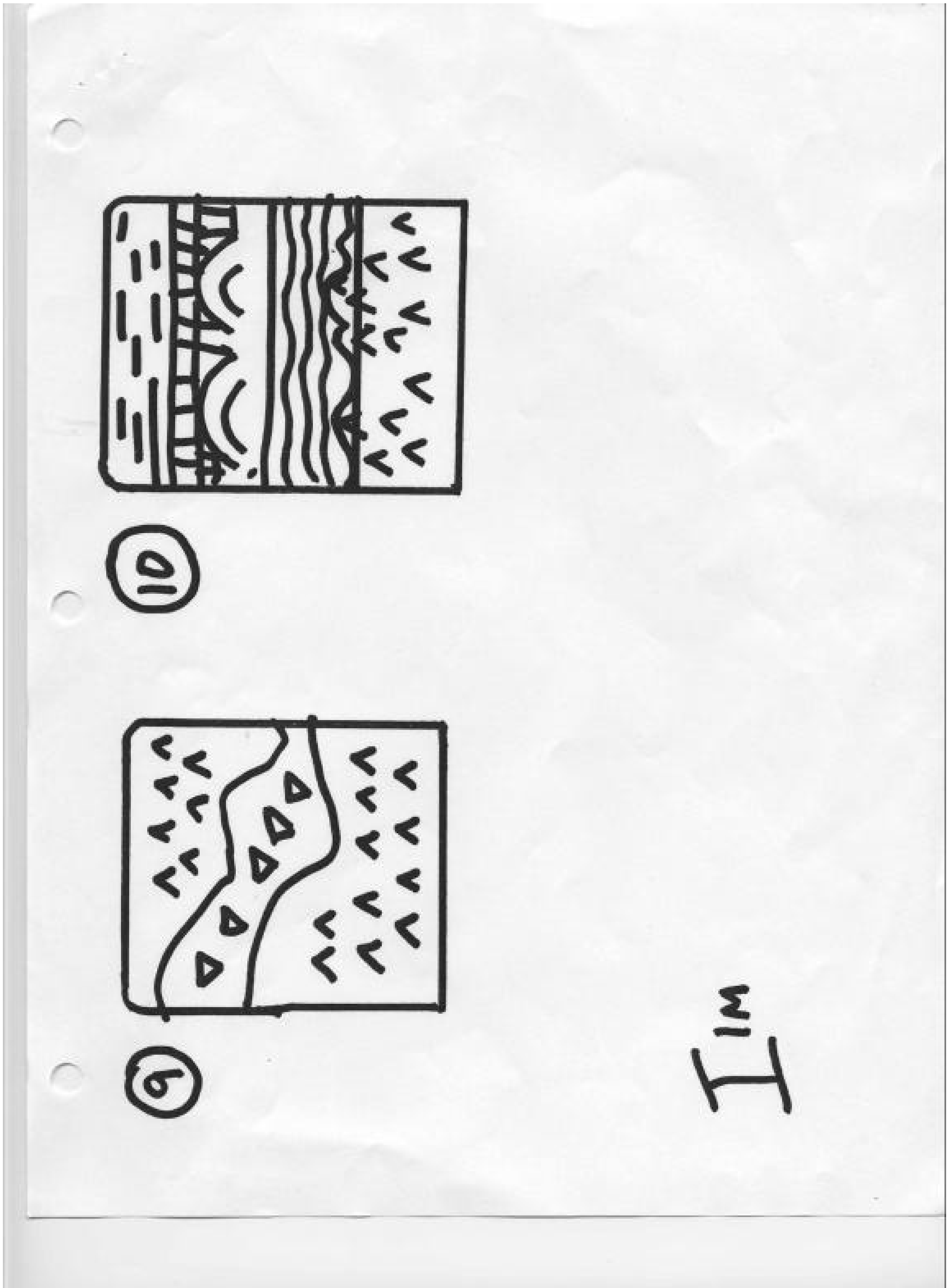
- Island Map
- Lithologic Columns for Selected Localities
- Lithologic Key

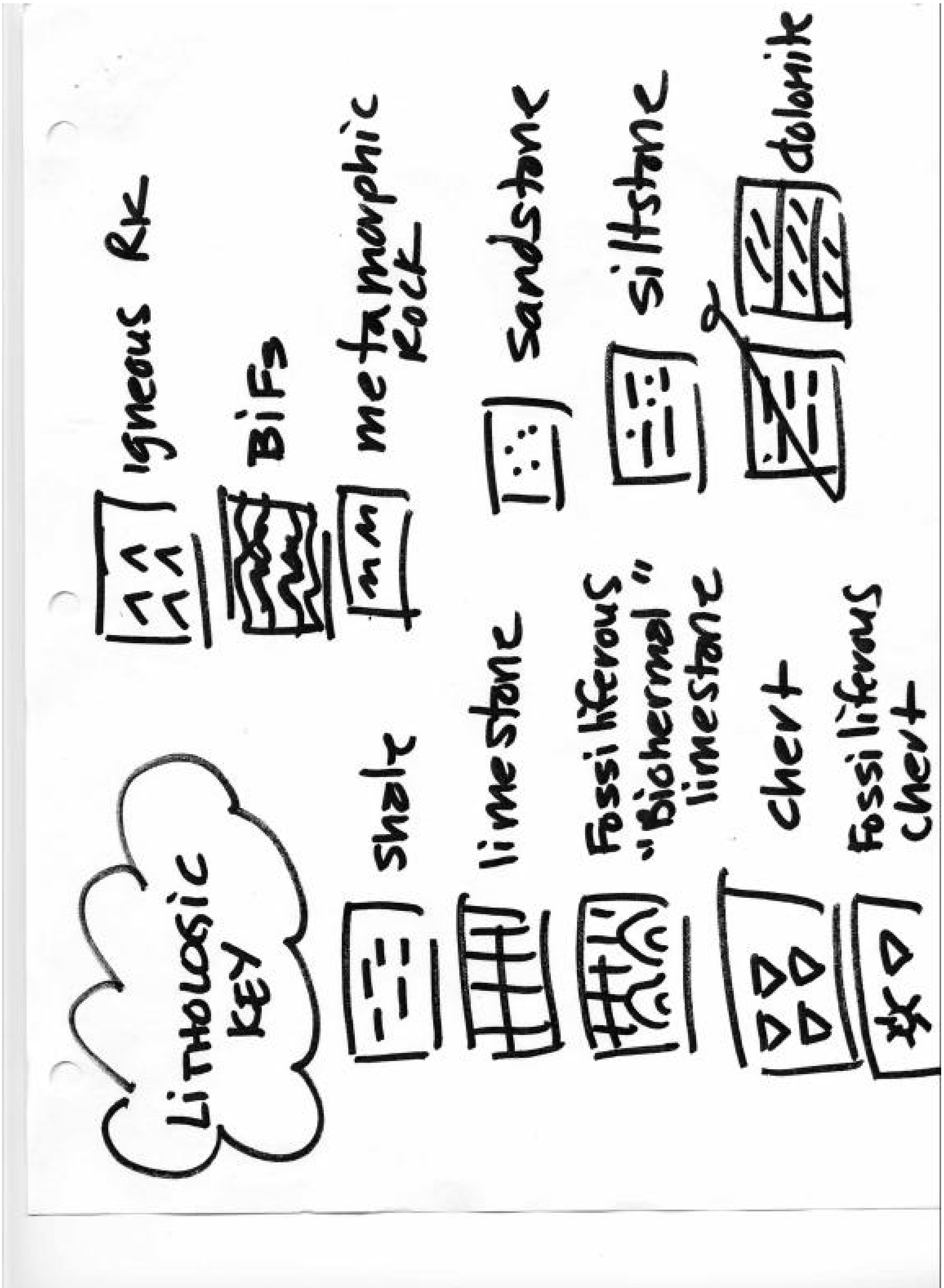

DANTE'S ISLAND
EAST HAGEN-DAS OCEAN
WEST HAGEN-DAS OCEAN
N
0 1 KM 2 KM
SCALE



LITHOLOGIC COLUMNS FOR SELECTED LOCALITIES
1
2
3
4
scale: 1M
(scale for all)




10
9
1m


Lithologic Key
shale
limestone
Fossiliferous "Biohermal" limestone
chert
Fossiliferous chert
igneous Rk
BIFs
metamorphic Rock
sandstone
siltstone
dolomite

SLAB/ SEDIMENT/ FOSSILS FINAL EXAM (TAKE-HOME)

GEOL XXXX, FALL 2004

NAME:
POINTS POSSIBLE: 200 pts **POINTS EARNED:**

You and John McPhee have just done some wondrous "geologizing" in the eastern half of the United States: you both went to Tennessee, Kentucky, and Georgia and collected some of the best fossils found in those areas. John McPhee needs you to help him write an essay on the geologic history of this area as represented by the slabs and fossils that you collected (represented by locality 1-4) incorporating the following information:

Knowing the history of the American craton, and your knowledge of fossils and rocks, you are able to piece together the following

1. Which localities (or locality) are from the interior of the American craton during periods of major sea onlap in the past. 10 pts.

2. Which localities (or locality) represent a more modern onlap to the eastern par to the American craton. 10 pts.

3. The time periods the localities represent, and the justification for those time periods. 50 pts.

4. The paleoecology, as represented by the fossils and associated sediments, of the localities. 50 pts.

5. How the history of the eastern craton of North America has changed over time n regard to evolutionary paleobiology: what are the major evolutionary trends in fossils and associated facies in this area during the time represented? Were there any major extinctions? Any major evolutionary adaptive radiations? What were the paleobiologic trends? 50 pts.

    a. Write up in John McPhee style: 30 pts.

Don't forget to use the *Treatise of Invertebrate Paleontology,* the *Index to North American Fossils,* your textbook, your notes, and you may also use the Internet to arrive at your answers (you may also discuss the ideas among yourselves, but please, do your own work; if I see duplicate verbatim answers for test, I will let you know my displeasure). Please make sure that you keep a data sheet on sediment types (carbonate vs. siliciclastic), sediment grain sizes (if applicable), the type of fossils (Phylum and lower level of classification – especially for any index fossils), the fossils geological range as specific as possible, and it's paleoecology (how it lives, what sediments it is found in, any taphonomic factors present, etc).

Appendix D

Participant Profiles

Participant Profile: Dr. Sanders

- 40 –something female
- Associate Professor in Geology
- Has taught this particular geology course for previous 6 years
- Introduced to DLESE in Spring 2004
- Experiences with inquiry-based learning in undergraduate and graduate school as a student
- Experience using inquiry-based learning approaches, but not constructing a complete course based on inquiry-based learning approaches

Participant Profile: Teaching Assistant

- 30-something male
- 1st year graduate student
- Has acted as an Adjunct Lecturer at a community college teaching introductory level courses in earth science, physical geology, weather, dinosaurs, and natural disasters
- Introduced to DLESE in Fall of 2004
- Prior experience with inquiry-based learning, occurred as a graduate student enrolled in an introductory level biology course that was re-designed to utilize inquiry-based teaching methods
- No experience teaching or facilitating learning using inquiry methods

Participant Profile: Jackson

- 20 year old male
- 3rd year student
- Geology major, Forestry minor
- 7 credit hours of geology (Earth processes and Environments; Historical Geology)
- Not currently enrolled in any other geology courses
- Other science background includes biology, chemistry and astronomy
- Comfort level with computers in learning: Not very comfortable
- Comfort level with the Internet and WWW in learning: Not very comfortable
- Familiar with DLESE prior to this course? - Yes

Participant Profile: Jake

- 22 year old male
- 5th year student (transferred from another school)
- Geology major, no minor
- Has 7 credit hours of geology (Physical Geology; Historical Geology)
- Currently enrolled in 3 other geology courses (Mineralogy, Surficial Processes, Geology Seminar)
- Other science background includes biology, chemistry and physics
- Comfort level with computers in learning: Very comfortable
- Comfort level with the Internet and WWW in learning: Very comfortable

- Familiar with DLESE prior to this course? - No

Participant Profile: Karen

- 20 year old female
- 3rd year student
- Geology major, no minor
- 12 credit hours of geology background (Physical Geology; Historical Geology; Geology Seminar; Geology Internship)
- Currently enrolled in 3 other geology courses (Mineralogy, Surficial Processes, Hydrology; Geology Seminar)
- Other science background includes chemistry and astronomy
- Comfort level with computers in learning: Very comfortable
- Comfort level with the Internet and WWW in learning: Very comfortable
- Familiar with DLESE prior to this course? - Yes

Participant Profile: Robin

- 20 year old female
- 3rd year student
- Geology major, Japanese minor
- 7 credit hours of geology background (Earth Processes; Earth's History of Global Change)
- Currently enrolled in 3 other geology courses (Mineralogy; Surficial Processes; Geology Seminar)
- Other science background includes biology and chemistry
- Comfort level with computers in learning: Very comfortable
- Comfort level with the Internet and WWW in learning: Very comfortable
- Familiar with DLESE prior to this course? – No

Participant Profile: Kyle

- 58 year old male
- Senior student – returning to college for a new career
- Geology major, Russian minor
- 6 credit hours of geology background (Physical Geology; Historical Geology)
- Currently enrolled in 4 other geology courses (Mineralogy, Surficial Processes, Hydrology; Geology Seminar)
- Comfort level with computers in learning: Comfortable
- Comfort level with the Internet and WWW in learning: Comfortable
- Familiar with DLESE prior to this course? - No

Participant Profile: Melanie

- 21 year old female
- 4th year student
- Anthropology major, Geology minor
- 11 credit hours of geology background (Physical Geology; Historical Geology; Geological Hazards)
- Not currently enrolled in any other geology courses
- Comfort level with computers in learning: Somewhat comfortable
- Comfort level with the Internet and WWW in learning: Comfortable
- Familiar with DLESE prior to this course? - Yes

Participant Profile: Drake

- 24 year old male
- 6th year student (returning after some time away from school)
- Geology major
- 20 credit hours of geology background (Physical Geology; Historical Geology; Mineralogy; Surficial Processes; Sedimentary Geology, etc.)
- Currently enrolled in 1 other geology course (Mineralogy)
- Comfort level with computers in learning: Very comfortable
- Comfort level with the Internet and WWW in learning: Very comfortable
- Familiar with DLESE prior to this course? - No

Appendix E

Interview Protocols

Student Interview 1

1. Tell me about your science background
2. Tell me about your geology background
3. Tell me about your previous experiences learning geology
4. Do you know what types of careers are available to you at the completion of your degree?
5. What does a geologist do?
6. What does science mean to you?
7. Describe your preferred method for learning? (i.e. lectures, hands on activities, etc)
8. What is your opinion of DLESE?
9. Now that you've been in the class for a while: how is it going?
10. What has been most difficult for you?
11. What would make learning easier for you?
12. What should have I have asked you about during this interview that I didn't?

Student Interview 2

So we are a little past the mid-point of the semester and you are in the full swing of the class. The last time I spoke with you – you were about 4 weeks into the course. So my first question for you again is:

1. Now that you've been in the class for a while: how is it going?
2. What has been most difficult for you?
3. What would make learning easier for you?
4. Lets talk a little bit about the labs:
    a. Talk me through the process of how you completed this [need to decide a common lab to ask each student about] lab
        i. What did you do in class
        ii. What did you do at home
        iii. What resources did you use
        iv. What did you learn from this lab
5. Tell me about your experiences using DLESE
    a. How frequently do you use DLESE
    b. How useful is DLESE for your learning in this class?
    c. How useful is it for your other classes?
6. Based on your experiences with DLESE thus far what changes if any would you recommend?
7. What should have I have asked you about during this interview that I didn't?

Student Interview 3

1. What did you find most interesting in this course?
2. What did you like most about the course?
3. How would you change what you didn't like about the course?
4. Which lab assignment did you enjoy most? Why?
5. Which lab assignment did you enjoy the least? Why?
6. One goal was to help you develop scientific critical thinking. Do you feel that this course has helped you develop scientific critical thinking? If so, how? If not, why not? (and what does that scientific critical thinking
7. Finally, this course aimed to help you develop your presentation and writing skills. Do you feel this course has helped you in these areas? If so, how? If not, why not?
8. How much do you think you learned in this course relative to other geology courses you have taken in the past? (more, less, about the same?)
9. You were not given a final exam on lecture content – how well do you feel you know/understand the material presented to you in lecture?
10. How well prepared do you think you were for the format of the final exam?
11. Do you think your score on the final is a fair representation of how much you learned in this course? Why or why not?
12. Do you think your final grade is a fair representation of how much you learned in this course? Why or why not?
13. Other comments/concerns?

Instructor Interview 1

1. So we are 2 weeks into the course thus far:
    a. What are your initial reactions to the course thus far?
        i. Students? Typical? Above normal? Below normal?
        ii. TA?
2. We have just completed the second lab:
    a. What are your impressions about how the first lab experience went?
        i. Did students accomplish the goals you set forth for them?
        ii. What would you change or do differently next time?
    b. What are your impressions of how the 2nd lab experience went?
        i. Did students accomplish the goals you set forth for them?
        ii. What would you change or do differently next time?
3. Anything else you want to share with me about your experiences teaching the course thus far?

Instructor Interview 2

Preamble:
Want to check in on how the course has progressed so far. We are a little more than halfway through the course so now is a good time to re-evaluate how things are working. So there are a number of issues that I want to make sure to address today so lets just start first of all with the lab assignments.

I think the last time we talked we had just completed lab 1 and 2; but you had not had the time to completely grade them. You've now had the opportunity to grade several of the labs to see how students are responding to them. Maybe we can go through each lab that we've done so far and see what you can recall about how students have responded to them and the quality of the products they have produced.

4. Lab X
    a. Goals for the lab
    b. Overall did students meet these goals?
    c. Problems you may have noticed?
    d. What might you change for next time?
5. Talk about some of the adjustments you have made in the course in response to students reactions thus far?

6. Tell me about what you have planned for students for the rest of the semester and what goals you might have for them with regards to what you would like them to accomplish/ learn?
7. With regards to DLESE – tell me a little bit about the DLESE project you are planning to do and what was the impetus for it?
8. Tell me about some of your experiences with DLESE
   a. Positives
   b. Negatives
9. Do you have any recommendations for ways that DLESE can be improved that would better suit your needs as an instructor? Your students needs?
10. Anything else you want to share with me about your experiences teaching the course thus far?

Final Instructor Interview (3)

1. What are your thoughts about how the course went this past semester?
   a. Students?
   b. TA?
   c. Lab assignments

I think the last time we talked we had just completed lab 6. Last time we went through several of the labs and you talked to me about the goals of each lab, your impressions of students performance on the labs, and how you might change the labs for next time. I would like to do the same thing for the last few labs that we did not cover last time.

2. Lab X (Labs 6, 7, & 8)
   a. Goals for the lab
   b. Overall did students meet these goals?
   c. Problems you may have noticed?
   d. What might you change for next time?

3. Impressions about the DLESE project?
   a. Will you do the DLESE project again with your students?
4. In previous interviews you mentioned concern about not having another exam on lecture content – what are your thoughts on this issue now that the semester is done?
5. Impressions about the final exam?
6. How much of a difference has DLESE made to your instruction? The way you teach?
7. What impact, if any, do you think having DLESE or the Internet available to students during lab time had on students learning?
8. Will/would you continue to provide students with Internet access during lab time?
9. Will you continue to promote DLESE as a resource to future students?
10. Do you think you will make greater use of DLESE in the future in your instruction?
11. What else can you share with me about your experiences teaching this course this past semester?

TA Interview 1

1. Tell me a little bit about your geology background
2. Tell me about your previous teaching experience
3. Describe your preferred teaching approach
4. How familiar are you with the content of the GEOL 4010 course?
5. So we are 2 weeks into the course thus far:
    a. What are your initial reactions to the course thus far?
        i. Students? Typical? Above normal? Below normal?
6. We have just completed the second lab:
    a. What are your impressions about how the first lab experience went?
        i. Do you think students accomplished the goals set forth for them?
    b. What are your impressions of how the 2nd lab experience went?
        i. Do you think students accomplished the goals set forth for them?
7. Anything else you want to share with me about your experiences being a TA for the course thus far?

TA Interview 2

1. From your perspective, how do you think the course is going so far?
    a. Any problems/ concerns
    b. What do you see working really well?
    c. What's your take on the students?
2. Tell me about your role as the TA
    a. Responsibilities/duties
    b. Interactions with students
    c. Understanding of course goals
        i. Facilitating inquiry-based learning
    d. Students grasping/understanding of material
3. Have you made use of DLESE?
    a. Tell me about some of your experiences with it
    b. Recommendations for improving DLESE?
4. What else can you share with me about your experiences as a TA in the course so far?

TA Interview 3

1. I would like you to reflect a bit on your experiences as a TA for this course.
    a. What made being a TA easy?
    b. What made being a TA challenging?
2. What skills/ knowledge do you think the TA for this course ought to have in order to effectively facilitate learning?
3. What suggestions if any do you have for the next TA of this course?
4. From your perspective, overall how do you think the course went?
5. I never got the opportunity to ask you about the field trip – can you tell me a little bit about your impressions of how the fieldtrip went?
    a. Did the students meet the goals set forth for them?
    b. Fieldtrip papers/ presentations?
6. How comfortable are you now facilitating learning in an inquiry-based learning environment? Tell me about your growth in this process over the semester? What factors were important in helping you become comfortable/confident with it?
7. Are there any problems or concerns you have with the lab that should be addressed the next time this course is taught?
8. Any final comments about your experiences as a TA for this course?

Appendix F

Questionnaires

Pre-course Survey

<u>DEMOGRAPHICS</u>

1. Name ___________________________

2. Age _____________

3. Gender ____________

4. What year of school are you in?

   ______ 1st year _____2nd year _______ 3rd year

   ______ 4th year ______ 5th year ______ Other (please explain on other side of page)

5. What is your present or intended:

   Major? _______________ Minor?_______________

EDUCATIONAL BACKGROUND

6. How many previous hours of Geology courses have you taken? (e.g. 6 credit hours)

   ___________ credit hours

   Please list the Geology courses you have taken.

7. What courses are you currently enrolled in? (Please list all *including* non-geology courses)

8. What types of science courses have you taken other than geology? (Check as many as apply)

____ Biology ______ Chemistry ____ Physics

____ Astronomy ______ Botany ____ Ecology

____ Other (Please list)

9. Inquiry-based learning is a student-centered, active learning approach focused on engaging students in a process of addressing scientific questions, gathering evidence, formulating explanations to address those questions, evaluating their explanations in light of alternatives, and communicating their findings.
(*Please circle a number below for each statement to indicate your response)*

a. How familiar are you with inquiry-based learning?

Not at all familiar 1 2 3 4 5 Very familiar

b. How comfortable do you think you will be with this learning approach?

Not at all comfortable 1 2 3 4 5 Very Comfortable

10. Please rate your comfort level with learning through group projects.

Not at all comfortable 1 2 3 4 5 Very Comfortable

TECHNOLOGY BACKGROUND

11. Please rate your comfort level with computers in learning.

Not at all comfortable 1 2 3 4 5 Very Comfortable

12. Please rate your comfort level with the Internet and World Wide Web in learning.

Not at all comfortable 1 2 3 4 5 Very Comfortable

13. How would you assess your skill level with each of the following?

(a) Word Processing Software (e.g. Word, Word Perfect)

Non-Existent 1 2 3 4 5 Expert

(b) E-mail

Non-Existent 1 2 3 4 5 Expert

(c) Using the Web

Non-Existent 1 2 3 4 5 Expert

OTHER

14. Were you familiar with DLESE (Digital Library for Earth Systems Education – www.dlese.org) before this class?

____ Yes ____ No

If yes, how/where did you learn about it?

____

____

____

15. What is your level of motivation for learning in this course?

Non-Existent 1 2 3 4 5 Highly Motivated

16. In this course you are expected to attend class for 3 hours per week, and participate in lab activities for 3 hours per week. In addition to the hours you will spend in the course and the lab, how many hours per week do you expect to spend on work/study related to this course?

__________ Hours

17. What else do you think I should know about you as it relates to this course?

Mid Semester Survey

Please respond to these questions honestly. Your comments about this course are extremely valuable and will be used to help make any needed changes to improve this course in the future.

1. What have you found most interesting in the course thus far?

2. Which lab assignments have you enjoyed the most? Why?

3. Which lab assignments have you enjoyed the least? Why?

4. What has been most challenging for you thus far in the course? Why?

5. How would you change what you don't like about the course?

6. How many hours per week do you spend (on average) outside of class and lab time on the following components of the course?

(a) Reading the text: ________

(b) Exploring related DLESE sites: _________

(c) Completing inquiry assignments _________

(d) Reviewing lecture notes/ ma terial: _________

7. How useful has DLESE been in supporting your learning in this course?

Not at all useful 1 2 3 4 5 Very useful

8. How useful has DLESE been in supporting your learning in your other courses?

Not at all useful 1 2 3 4 5 Very useful

9. What problems have you had understanding how to use DLESE? (Check as many as apply)

____ None, I have not made use of DLESE this semester

____ Not enough guidance provided

____ Navigation not clear

____ Search features not clear

____ Other (please specify) ___________________________________

____ None, I have experienced no problems understanding how to use DLESE

10. What additional comments/concerns do you have about this class that you wish to share?

End of Course Survey

1. Please rate the impact of the following factors on your understanding of material in this class: Also explain why you gave it that rating

   a. Textbook
      No impact 1 2 3 4 5 Considerable impact
      (didn't help understanding) (helped understanding a lot)

   b. Instructor
      No impact 1 2 3 4 5 Considerable impact

   c. TA
      No impact 1 2 3 4 5 Considerable impact

   d. Classmates
      No impact 1 2 3 4 5 Considerable impact

   e. Resources found on DLESE
      No impact 1 2 3 4 5 Considerable impact

   f. Group work
      No impact 1 2 3 4 5 Considerable impact

   g. Paleo-notes
      No impact 1 2 3 4 5 Considerable impact

   h. Monteagle Fieldtrip
      No impact 1 2 3 4 5 Considerable impact

   i. Fieldtrip paper/presentation
      No impact 1 2 3 4 5 Considerable impact

   j. DLESE project
      No impact 1 2 3 4 5 Considerable impact

   k. Other factors ?
      No impact 1 2 3 4 5 Considerable impact

2. How many hours per week did you spend (on average) outside of class and lab time on the following components of the course?

   (a) Reading the text: ________

   (b) Exploring related DLESE sites: ________

(c) Completing lab assignments _________

(d) Studying: _________

3. How helpful was it to have DLESE available to you during lab time?

Not at all helpful 1 2 3 4 5 Very helpful

4. How helpful was it to have Internet access available to you during lab time?

Not at all helpful 1 2 3 4 5 Very helpful

5. What problems did you have understanding how to use DLESE?

____ Not enough guidance provided

____ Navigation not clear

____ Search features not clear

____ Technical (e.g. websites/ resources found did not work)

____ Other (please specify) ________________________________

____ None, I experienced no problems understanding how to use DLESE

6. Please rate your knowledge/understanding of the following concepts:

a. Rock types
Pre- course
No knowledge 1 2 3 4 5 Proficient

Post- course
No knowledge 1 2 3 4 5 Proficient

b. Depositional environments
Pre- course
No knowledge 1 2 3 4 5 Proficient

Post- course
No knowledge 1 2 3 4 5 Proficient

c. Biogenicity criteria for recognizing life
Pre- course
No knowledge 1 2 3 4 5 Proficient

Post- course
No knowledge 1 2 3 4 5 Proficient

d. Evolution of eukaryotes (how & when originated, and how to recognize)
Pre- course
No knowledge 1 2 3 4 5 Proficient

Post- course
No knowledge 1 2 3 4 5 Proficient

e. Protists (recognition of different types)
Pre- course
No knowledge 1 2 3 4 5 Proficient

Post- course
No knowledge 1 2 3 4 5 Proficient

f. Preservational modes (recognizing preservational states for a sample)
Pre- course
No knowledge 1 2 3 4 5 Proficient

Post- course
No knowledge 1 2 3 4 5 Proficient

g. Scientific criteria for classifying bauplanes (e.g. symmetry, # of stem cells, etc.)
Pre- course
No knowledge 1 2 3 4 5 Proficient

Post- course
No knowledge 1 2 3 4 5 Proficient

h. Invertebrate phyla (types/recognition of)
Pre- course
No knowledge 1 2 3 4 5 Proficient

Post- course
No knowledge 1 2 3 4 5 Proficient

i. Comparative paleontology of Paleozoic fossil organisms (e.g. telling the difference b/t Phyla Porifera, Achaeocyathida, Cnidaria, Brachiopoda, Ectoprocta, & Anthropoda)
Pre- course
No knowledge 1 2 3 4 5 Proficient

Post- course
No knowledge 1 2 3 4 5 Proficient

j. Comparative paleontology of Mesozoic Mollusca fossils (e.g Class Gastropoda, Bivalvia, Cephalopoda)

Pre- course
No knowledge 1 2 3 4 5 Proficient

Post- course
No knowledge 1 2 3 4 5 Proficient

k. Geerat Vermeij's Marine Revolution hypothesis

Pre- course
No knowledge 1 2 3 4 5 Proficient

Post- course
No knowledge 1 2 3 4 5 Proficient

l. Evolutionary trends in deuterostomes (echinoderms and vertebrates)

Pre- course
No knowledge 1 2 3 4 5 Proficient

Post- course
No knowledge 1 2 3 4 5 Proficient

7. One goal of this course was to help you learn the applied aspect of paleoenvironmental analysis and relative age-dating by using fossil organisms. Please rate your knowledge/ skill level of this process both *before* and *at the completion* of this course.

Pre- course
No knowledge 1 2 3 4 5 Proficient

Post- course
No knowledge 1 2 3 4 5 Proficient

Appendix G

Course Syllabus

GEOL XXXX	SCHEDULE FALL 2004	Readings/Items Due
19 Aug	Lecture 1: Introduction to Course	
24 Aug	Lecture 2: Importance of the Fossil Record	Lecture: Chap. 1-Chap. 2
26 Aug	Lecture 3: Major Rock Types and Biofacies Applications	Lecture & lab: Handouts
	Lab 1: Where in the world is Carmen Miranda? Traverse across western Terrane	Lab Quiz on Handouts
31 Aug,	Lecture 4: Earth's Earliest Life and Habitats (debate information given)	Lecture: Chap. 3; Chap. 19, p. 437-440; Readings from *Nature* and *Science*
2 Sept	Lecture 4 continued Lab 1 finishes	
7 Sept	Lecture 5: The Proterozoic Revolution and Trace Fossils	Lecture: Chap. 4, pp. 51-63 (cladistics);
9 Sept	Lecture 5 continued Lab 2: Earth's Earliest Archaean Life Forms and biogenicity debate	Lab: handouts
14 Sept	Lecture 6: Cambrian Explosion: Evolution of Skeletons	Lecture: Chap. 5
16 Sept	Lecture 6 continued & review for Exam 1 Lab 3: Proterozoic Innovations in Body Forms including Trace Fossils	Lecture & Lab: Chap. 4 ; Chap. 18 Lab Quiz on Trace Fossil Reading (Chap. 18)
21 Sept	Exam No. 1	Exam No. 1
23 Sept	Lecture 6 continued; Sapelo field info. Lab 4: Smallest Shells on Earth: Foraminifera	Lab: Chap. 11
24-26 Sept	Sapelo Field Trip and Sapelo Project: Sediments and Biofacies	Weekend Trip to Sapelo
28 Sept	Lecture 7: "Evo-Devo" and Deriving Bauplanes	Lecture: Chap. 4 & 5; Prokaryotes to Eukarotes Cladogram Homework
30 Sept	Lecture 7 continued Lab 5: Taphonomy: Perils of Preservation	

		Lab: Refer back to Chap. 1; handouts
5 Oct	Lecture 8: Perils of Preservation	Refer back to Chap. 1; handouts
7Oct	Prepare for Sapelo Symposium Lab 6: Sapelo Symposium	Presentations and papers due
12 Oct	Lecture 9: Paleozoic Evolutionary Groups, Diversity and Mass Extinctions	MIDPOINT
14 Oct	Lecture 9 Paleozoic continued Lab 7: Paleozoic Evolutionary Groups	Lab: Chap. 12 & 13; Lab Quiz on those chapters
19 Oct	Lecture 9 continued (terrestrialization)	Lecture: Chap. 17, p. 343-366; 370-381. Chap. 19, pp. 440-451.
21 Oct	Lecture 9 continued (terrestrialization) Lab 7 continued: Paleozoic Evolutionary Groups	DLESE Abstract & Outline of project due. Lab: Chap. 12, 13 & 14
26 Oct	Lecture 10: Paleozoic Marine and Terrestrial Mass Extinctions	Lecture: Chap. 6
28 Oct	Fall Break; no lab/lecture	Fall Break no lab/lecture
2 Nov	Lecture 11: A Mesozoic Marine and Terrestrial Revolution? Functional Morphology of Predator: Prey Interactions	Lecture: Chap. 7
4 Nov	Lecture 11 continued Lab 8: Meddling in the Mesozoic: Fossils, Facies, and Time	Chap. 15; Chap. 17, pp. 363-370; 377-393; Chap. 19, pp. 452-461. Lab Quiz on those chapters.
9, 11 Nov	Finish Lab 8 and prepare DLESE project proposal & justification presentation for 16 November	GSA WEEK
16 Nov	Lecture 12: Presentation DLESE project proposal & justification	DLESE Proposal Presentation
18 Nov	Lecture 13: Evolution of Cenozoic marine and terrestrial paleoecology Lab 9: Major trends in Cenozoic marine and Terrestrial ecosystems	Lecture: Chap. 8 Lab: Chap. 16; Chap. 17, pp. 394-417; review Chap. 19, pp. 455-461.

23 Nov	Lecture 13 Cenozoic, continued	Lab Quiz on those chapters.
24-26 Nov	Thanksgiving Holiday	No classes
30 Nov	Work on your DLESE presentation and web site	
2 Dec	Lab/Lecture: DLESE Website Presentation Handout Take-Home Slab/Fossil Final	Presentation/web site due
7 Dec	Open workshop for Take-Home Exam (ask me questions!)	
14 Dec	Slab/Fossil Take-Home final due	Final due by 5 PM Tuesday, 14 Dec 2004

GEOL XXXX LIFE, ENVIRONMENTS AND ECOLOGIES OF THE PAST FALL 2004
[Professor Contact Information Here]

[Lab Teaching Assistant Contact Information Here]

Class: Lecture: Tues-Thurs 11: 00—12:15 pm.
Lab: Thurs, 12:30-3:15 pm

Goals: To understand the major events in biotic evolution from Precambrian to Phanerozoic time and learn applied aspects of paleoenvironmental analysis and relative age-dating using fossil organisms. To achieve these goals, scientific critical thinking, presentation and writing skills will be emphasized.

The lectures will serve to provide you with basic information that you will then have the opportunity to apply to problems and scenarios in the laboratory component of the course. In the lab, you will also have the opportunity to make use of the resources available from the DLESE website. DLESE is the Digital Library for Earth System Education, a geoscience community resource that supports teaching and learning about the Earth system. DLESE provides access to numerous resources for teaching and learning; interfaces and tools for student exploration of Earth data; services to create, use, and evaluate digital learning resources; and a community center to foster interaction, collaboration and sharing among scientists, students and teachers.

Class Etiquette: I expect that you will always attend lecture and lab and to be on time to each lecture/lab; for those who don't, you will receive no credit for lectures/labs missed. Medical or other emergencies will need legitimate written or other excuses; please contact me in advance of any prior commitments that you may have for your own grade protection! Please put your cell phones to quiet mode, and unless there is an emergency, please do not answer the cell phone in class. Attendance: I will take attendance every day; if you miss more than three lecture classes, I will withdraw you from the class; if you do not come to lab, you will be given a zero for that lab (thus losing 40 pts for each lab missed) unless you have an authorized medical (or other) excuse.

Grades: Your final grade is based on your performance and the performance of your peers. Collaborative and individual work is encouraged. Those that collaborate will share a similar grade (unless otherwise argued). However, I will assign you to different groups for various projects, so you will not always have the same collaborator for projects or labs. I grade on a curve.

Distribution of Points for GEOL 4010 as evenly divided as possible:

Lab Quizzes based on lab readings (5 quizzes total)	20 pts each; 100 pts total
Exam 1	100 pts
Take Home Slab/fossil Final Exam	150 pts
Sapelo Field Notebook (Field Book)	50 pts
Sapelo Research Project	100 pts
Sapelo Research Presentation	100 pts
Biogenicity Debate (in lab)	50 pts
Lab Reports (9 reports)	40 pts each; total 360 pts
DLESE web project	Abstract & outline (20 pts); preliminary DLESE project proposal and justification presentation/writeup(80 pts); Final DLESE presentation (100 pts); final DLESE web site (100 pts); total 300 pts
Total Points:	1310 pts

Readings & Labs: Assigned readings should be completed before class and labs. Labs are due at the beginning of Monday's lecture (i.e., the week following the lab) unless otherwise specified. No late work is accepted for any assignment, for any reason.

Textbook and other needs: Prothero, *Bringing Fossils to Life*; Handlens with cord for hanging around neck; mm scale; Loose-leaf binder with drawing paper; pencils; field notebook for Sapelo Island and DLESE notes.

PLEASE DO NOT USE PEN IN LAB; USE PENCIL.

Appendix H

Characterization of Inquiry Tasks Based on the NSES Essential Features of Inquiry

Essential Feature: Learner engages in scientifically oriented questions

Variations of Feature (Decreasing in amount of learner self-direction)	Classification of Lab Activity
Learner poses a question	
Learner selects among questions, poses new questions	
Learner sharpens or clarifies question provided by teacher, materials, or other source	
Learner engages in question provided by teacher, materials, or other source	Lab 1, Lab 2, Lab 3, Lab 5

Essential Feature: Learner gives priority to evidence in responding to questions

Variations of Feature (Decreasing in amount of learner self-direction)	Classification of Lab Activity
Learner determines what constitutes evidence and collects it	
Learner directed to collect certain data	Lab 1, Lab 2, Lab 3, Lab 5
Learner given data and asked to analyzed	
Learner given data and told how to analyze	

Essential Feature: Learner formulates explanations from evidence

Variations of Feature (Decreasing in amount of learner self-direction)	Classification of Lab Activity
Learner formulates explanation after summarizing evidence	Lab 1, Lab 2, Lab 3, Lab 5
Learner guided in process of formulating explanations from evidence	
Learner given possible ways to use evidence to formulate explanation	
Learner provided with evidence	

Essential Feature: Learner connects explanations to scientific knowledge

Variations of Feature (Decreasing in amount of learner self-direction)	Classification of Lab Activity
Learner independently examines other resources and forms the links to explanations	
Learner directed toward areas and sources of scientific knowledge	Lab 1, Lab 2, Lab 3, Lab 5
Learner given possible connections	

Essential Feature: Learner communicates and justifies explanations

Variations of Feature (Decreasing in amount of learner self-direction)	Classification of Lab Activity
Learner forms reasonable and logical argument to communicate explanations	Lab 1, Lab 2, Lab 3, Lab 5
Learner coached in development of communication	
Learner provided broad guidelines to sharpen communication	
Learner given steps and procedures for communication	

Appendix I

Inquiry-based Tasks

LAB 1: ROCKS AS GUIDES TO TECTONICS AND ENVIRONMENTS

INTRODUCTION/GOALS OF LAB:

Fossils occur in a variety of sedimentary depositional environments, from carbonates to clastics (siliciclastics). Fossils, such as conodonts, may even occur in metamorphic rocks, and rarely, fossils are found in igneous rocks. Consequently, while most fossils occur in sedimentary rocks, there are exceptions. Therefore, we must be familiar with the major rock types, to address the depositional history and/or tectonic history of the fossils.

In lab today, you will examine the three major rock types (igneous, metamorphic, and sedimentary rocks) to determine their constituent common minerals, and identify the rocks that contribute the most to silicilastic and/or carbonate depositional environments through weathering and erosion. You will also construct a rock cycle, based on the rocks in lab--that is, how all rocks are related through various geological processes.

Major Rock Types.

Why are the major rock types important to examine? First, as mentioned earlier, fossils can occur in all the major rock types, but remember that fossils are most common in sedimentary rocks. We'll explore sedimentary rocks in depth in Laboratory 2.

If you become familiar with the major rocks on earth, you can then be able to decipher earth's processes, such as plate tectonics, paleoclimates, paleoenvironments and evolution through time. Threfore, it is important to not only to recognize the major rock types, but also what they may signify in terms of tectonics, environment, or evolutionary change. In this lab, you will learn to "read" those various types of signals embedded in the wondrous rock record. If you already know the characteristics of the three rock types, you may proceed to the "Applied Geology" section. If you are a bit hazy on the major rock types, please read the "Geo-Sidebar" section (below).

GEO-SIDE BAR: THREE MAJOR ROCK TYPES

Igneous rocks. Igneous rocks result from cooling of molten magma and/or lava. The molten material (magma--which is below the earth's surface, and lava which is above the earth's surface) "freeze" at temperatures between 650^{o}C and 1100^{o} C (home ovens only reach a maximum temperature of 260^{o}C!). Igneous rocks are the most common of all rock types, comprising the mantle, ocean crust, and a majority of the continental crust.

There are intrusive and extrusive igneous rocks. Intrusive igneous rocks intrude within preexisting crust, and cools below the earth's surface. Extrusive rocks cool above the earth's surface. Extrusive rocks can be basalts, andesitic flows, ash (glass shards), and pyroclastic debris to name a few.

Igneous rocks are classified based on their texture and composition. Texture refers to the way the igneous rock looks, whether it is glassy (non-crystalline), vesicular (non-crystalline with bubble texture), porphyritic (contains two different size mineral grains: large phenocrysts and smaller microcrystalline groundmass), aphanitic (microscopic interlocking crystal structure) and phaneritic (large, interlocking crystals). In general, intrusive rocks are phaneritic, and extrusive rocks are vesicular, glassy, aphanitic and/or porphyritic (such as porphyritic basalt). Intrusive rocks can also be porphyritic (such as porphryitic granite).

Composition is based on the rocks mineral content. Igneous rocks are either felsic or mafic in composition. Felsic rocks are composed dominanty of alumino-silicates (feldspars and quartz), and are light in color. Mafic rocks are composed of mostly iron and magnesium, and are dark in color (from olivine, pyroxene, and iron minerals for example. In general, felsic rocks are continental rocks, and mafic rocks are ocean crust rocks. Specific gravity, which places a big role in the mechanism for plate tectonics, also differs between mafic and felsic rocks. Mafic rocks have a specific gravity around 2.8 g/cm3; felsic rocks, 2.6 g/cm3. Specific gravity is the density of a mineral divided by the density of water. Because water has a density of 1 gram/cm3, and because all of the units cancel, specific gravity is the same number as density but without any units.

Refresh your memories on igneous rocks by visiting DLESE web sites (www.dlese.org).

Metamorphic Rocks. Metamorphic rocks form from the combination of heat and pressure within the earth's surface. Metamorphic rocks result from other rocks that have changed in the solid state to another rock! That is, metamorphic rocks can be formed from sedimentary, igneous, or other metamorphic rocks.

Metamorphism can replace a rock's original crystal composition with a new composition (recrystallization), depending on the type of protolith (original rock composition), temperature and pressure. Typically, temperatures between 250^{o}C and 700^{o}C are required for metamorphism and pressures between 2 and 8 kbars. (A "kbar" is a thousand x 1 barometruc pressure (bar). 1 bar = 0.9869 atmosphere (atm) = 1.02 kg/cm^{2}). Increased temperatures and pressures can occur in areas by heat (igneous processes), hot groundwater, pressure (burial within the earth), and differential stress from tectonics.

Metamorphic rocks that form under low temperature conditions (usually below 320^{o}C) are called low-grade metamorphic rocks. Such rocks may include the metamorphism of shale into slate; with higher temperatures, the slate may metamorphose into phyllite. At even higher temperatures, the phyllite may metamorphose into schist or gneiss. These last metamorphic rocks are called high-grade metamorphic rocks (rocks forming over 500^{o}C).

Metamorphic rocks have two distinguishing characteristics: first, a particular suite of minerals that result primarily from metamorphism, and second, metamorphic foliation (resulting from mineral layers within the rock that are segregated into layers by temperature and pressure or orientation of minerals due to stress).

There are two types of metamorphic rocks: foliated and non-foliated rocks which are distinguished by their mineral composition, grain size, and if applicable, the type of foliation.

Foliated metamorphic rocks have either minerals aligned in a preferred parallel orientation or compositional banding, where light and dark minerals are separated. There are numerous types of foliated rocks, including a famous one from Athens, Georgia. Refer to DLESE (or, if you Google a great site, let us know, so we can notify DLESE) if you can not remember these types of rocks.

Nonfoliated metamorphic rocks have recrystallized minerals but usually has no recognizable foliation (there are exceptions). A famous non-foliated metamorphic rock comes from the metamorphism of limestone. What might that be? Another non-foliated metamorphic rock comes from the metamorphism of sandstone. Can you think of its name?

Refresh your memories concerning metamorphic rocks on the DLESE website.

Sedimentary Rocks. Sedimentary rocks form from the weathering and erosion of pre-existing rocks. Weathering refers to the process that breaks up or chemical corrodes rock; erosion, to the transport of the resulting sediments. Thus, rocks can be weathered by ice (frost wedging) or lichen (acid-etching), and eroded by water or wind. (Water and wind can also weather the rocks, as water is a weak acid and wind can physically abrade the rock). Sediment is usually loose rock fragments, grains of minerals, precipitated minerals from either physical or biological agents. Sedimentary rock, unlike metamoprhic or igneous rocks, are formed exclusively at the Earth's surface. Sedimentary rocks, then, are important for determining past environments, climates and organisms--that precipate minerals to build their skeletons.

Sedimentary rocks cover more than 80% of the Earth's surface, but compared to igneous and metamophic rocks, they only make up a small portion of the Earth's mass.

There are four main types of sedimentary rocks: 1) clastic (detrital) rocks, which derived from siliceous-rich felsic rocks or mafic rocks. Clastic just refers to a rock fragment. Usually, felsic rocks--derived from terrigenous siliceous Quartz rich rocks are termed siliciclastic rocks or siliceous rocks because they contain a high degree of quartz minerals. Sediments derived from the erosion of basalts and/or igneous mafic rocks are called volcaniclastic rocks; volcaniclastic rocks can also form from volcanically-induced mudflows. 2)biochemical sedimentary rocks consist of skeletons (shells or bones) from organisms that precipitate minerals. Many of these rocks can also be called carbonate rocks depending on their composition. 3) Organic, composed of carbon-rich deposits (coal) formed from the superficial burial of plant debris. And, 4) chemical sedimentary rocks which precipitate out of solution, usually in arid conditions. Examples of chemical sed rks are the evaporites: halite (NaCl), gypsum ($CaSO4x2H20$), and anhydrite ($CaSO4$). Note, these rocks are also considered minerals.

Refer to DLESE web site for additional information and common sedimentary rock types. Also, please review the GEOL 1260/GEOL 1122 compilation provided for you.

APPLIED GEOLOGY PROBLEM

1. Rock samples have been collected from the American west, comprising what is now Oregon and Washington, U.S.A. (see map provided).

The Problem

A major problem concerns whether these rock samples provided for this applied geology problem contain any information in regard to plate tectonics --that is, do the rocks indicate the assembly of western North America in any way? Given the suite of rocks, would you conclude that western North America was an active or passive margin? Additionally, do the rocks indicate any major environments that occurred in these areas in the past? You can use the map information to interpret geologic time and/or environments as well. For selected rock types found in this lab, how are they related to the rock cycle?

How to Approach the Problem

First, decide how you want to organize your data collection in relation to the questions being asked. How would you construct your data table? This data table is important, and will be turned in as a typed data table with your research synopsis of this problem.

Second, decide on a method of collecting your data that you do not waver from. In science, it is important to co llect data in the same way, even though it gets tedious. If you do decide to change your method because you realize you are not answering your question, then you need to start all over a gain with a new method! But, this happens in science, so don't worry!

Third, make sure you write down your collection methods, and how you collect your data so that, say, years from now, you can interpret the data you collected.

Fourth, analyze your data--what types of igneous, metamorphic and sedimentary rocks do you have? And, where do they plot out on the map? Do they represent any tectonic and/or depositional environments?

Finally, summarize your research findings in regard to the questions for this lab.

You may consult any books, web sites, TA, colleagues and your professor to help you with your data collection and analysis. At the end of the lab, we will have a debriefing session where we will discuss our individual findings and progress toward solving the problem.

Lab 2: Biogenicity and Earth's Earliest Life
(subtitled, "*Earth's Earliest Life and Biogenicity Debate*")

Note, a biogenicity critique of the paper you read (either Schopf or Brasier's) will be due with this lab write up on Tuesday, Sept. 14, 2004

This lab shall be typed (data can be in pencil, sketches can be in pencil and attached to the lab) and due on Tuesday, Sept. 2004.

One of the most pressing questions in paleobiology and astrobiology today concerns the criteria by which we recognize life on earth. Can criteria for life on Earth be directly used to recognize life on other planets? In this lab you will be using a variety of sources to help with this pressing question: fossils, micrographs (high-resolution photographs), thin sections, *Nature* and *Science* readings, and the web site DLESE (or additional web information, such as the Georgia Library's Galileo database or NASA).

The main questions that you will be tackling in this lab today are:

1) Develop biogenicity criteria for recognizing life forms in ancient Archean Eon rocks. What types of information would you be looking for, and how would you analyze it?

2) Can the criteria you develop for Archaen rocks be used to recognize life on other planets?

You have a series of workstations that are set up to help you with the questions listed above.
YOU NEED TO DO THE WORK STATIONS IN CONSECUTIVE ORDER!

I. Work Station No. 1. First, discuss in your groups (or individually!) the biological criteria for life that you are most familiar with from your background and make a list of these criteria. Second, check your list with DLESE and/or google criteria for ancient life on earth and compare that information to yours. Type up your information in tabular format. Lastly, determine which of the criteria you would use for the rest of this lab. You would use the criteria as a "working hypothesis" and you need to stick with this hypothesis throughout the lab. If you find this in untenable, then keep track of your criteria changes, and jot down why you made the changes to the criteria you are using for this lab.

II. Work Station No. 2. The thin sections at this workstation may have living and non-living matter in them.

A. Using the criteria you developed in Work Station No. 1, can you determine which slides (B-7, B-10, & 29-49) are life forms, or just sediments? Sketch each sample using a representative from each of the slides. Be sure to include magnification and scale if applicable. Please give your evidence and justification for your interpretation.

B. Examine the histological-tissue thin sections (labeled 2a, 2b, 2c) and determine if they fit your criteria for what a life form is. Next, for each thin section, determine if the life forms (if they *are indeed* life forms) are prokaryotic or eukaryotic and give evidence for your reasoning.

III. Work Station No. 3: Please examine the polished hand specimens. These rocks are what geologists would commonly see in the field if they studied the Archaean Eon system. One of the most difficult challenges is to determine if these rocks may hold biogenic information. Thus, of the rocks in this workstation, which ones may be biogenic? Give evidence for your reasoning. Are there any rocks here that you can name specifically? Finally, what additional information or technique would you use to clearly establish whether these rocks contained early life forms?

IV. Work Station No. 4: At this station, you have both polished hand specimens and petrographic thin sections that have come directly from these hand specimens. Please examine both the hand specimens and thin sections carefully.

A. Determine what type of information you can retrieve from the hand specimen in relation to the question of biogenicity.

B. What type of geologic information do the petrographic thin sections give you?

C. Can you now attempt to answer the two questions posed at the beginning of this lab? Explain your reasoning/hypotheses.

V. Work Station No. 5: You have found these specimens under a snow bank in Glacier National Park. These rocks were *in situ*, and you used your rock hammer (sledge hammer!) to get them out of the outcrop, and you polished some of these hand specimens so you could see the interior of the rock without weathering obscuring your view.

A. What is your interpretation of these rocks? Explain and justify evidence.

B. If these rocks are 1.2 billion years old, can you determine the climate that these ancient rocks may have represented? (i.e., arctic conditions, temperate conditions, subtropical conditions, tropical conditions). Explain your answer.

C. What does the color of the rock tell you about the atmosphere 1.2 billion years ago? Explain and give evidence.

VI. Work Station No. 6: Schopf versus Brasier Biogenicty Debate Concerning the Oldest Body Fossils on Earth, the 3.5 Billion-Year-Old Apex Chert Microfossils. You will debate the controversy over recognizing the earliest of Earth's life forms. At the end of the lab today, we will debate the issues starting at 230 PM (or earlier if you want). Please write up a short critique (critical review of the paper) based on the paper that you read for the debate. Consider these topics when writing your critique: 1) do the authors try to refute their hypothesis, or do they try to support it? 2) What questions and methods do the authors use to answer the question of biogenicity? 3) What do their results indicate? 4) Are their conclusions valid? Or, are they missing some information that they should have included? Explain and/or justify your statements. This critique will be typed, double-spaced (with 1.5 inch margins), and up to four pages, with 1 inch margins. Turn in the critique with this lab next Tuesday, Sept. 14.

NOTES:

Lab 3: The Protozeroic Revolution: The Origin of Eukaryotes

<u>This lab is due Thursday, Sept. 23, 2004 by 5 pm</u>.

A major question in paleobiology is how did we get so many organisms on earth, with the incredible breadth of diversity. In Lab 2, we focused on the single-celled organisms (bacteria, archaebacteria) and in Lab 3, we will focus on the multi-cellular revolution in Eukaryotes.

Questions to ponder and to synthesis for your final lab report are the following:

1. What are eukaryotes?

2. How and when did they originate?

3. What are the first eukaryotes in the fossil record from the Proterozoic Eon, and how are they recognized (criteria)?

The workstations are organized to help with answers to these questions.

If you would like to read more about this exciting time in Earth's history, please read this new book: Andrew H. Knoll, 2003, *Life on a Young Planet: The First Three Billion Years of Evolution on Earth.* Princeton University Press, Princeton. 277 pages.

I. <u>Work Station No. 1</u>. Major theory concerning eukaryote evolution: Endosymbiosis. We will watch the video concerning Lynn Margulis and her theory concerning how eukaryotes arose, which is endosymbiosis.

A. What is the evidence presented in the video concerning endosymbiosis?

B. Are there any particular experiments that show the process of endosymbiosis?

C. What are some examples of endosymbiotic organisms, and how did they become endosymbiots?

D. How is the theory of endosymbiosis different than or similar to natural selection?

E. Do you feel that endosymbiosis accounts for eukaryotic origins? Suggest another or compatible evolutionary process that may account for the origin of eukaryotes. You may use DLESE, Galileo-UGA and/or *Google* to arrive at your answer.

II. <u>Work Station No. 2</u>. What is a eukaryote?

A. First, delineate the scientific criteria you would use to distinguish eukaryotic organisms from prokaryotes <u>both theoretically and practically in the fossil record</u>.

B. Second, apply your criteria to the Proterozoic micrographs provided in this work station.

C. Third, which of the micrographs represent eukaryotes? Which micrographs represent prokaryotes? What is the evidence that you used for your interpretations?

D. Fourth, do these micrographs support your evidence for life forms developed in Lab 2?

E. Finally, can you place the micrographic evidence in <u>hierarchical order</u>, from simple to complex organisms? Would this structural order reflect the actual chronological order of these fossils in the record (i.e, which forms would occur first in the fossil record? Next in the fossil record? Which would be the youngest Proterozoic life form?)?

III. <u>Work Station No. 3</u> At approximately 695 million years ago, the oldest multicellular eukaryotic organisms on Earth originated. Their fossil range extends approximately 150 million years, up into the early Phanerozoic Eon (the early Cambrian Period). These organisms are called the <u>Ediacaran Fauna</u> (also known as: <u>Vendian Biota</u> or <u>Vendobionts</u>). They were originally discovered in the Ediacaran Hills, Flinders Ranges, South Australia. They are impressions found in the "Pound Quarzite", a well-indurated sandstone. You have actual plaster CASTS of these organisms hailing from the world famous Australian deposit.

Examine the photos I took of the Ediacaran Hills,and the organisms in addition to examining the plaster casts and two of Ben Waggoner's dental-putty molds that he gave me for this class.

3A. How were the original organisms preserved? Do you usually get excellent preservation in siliciclastic sandstones? Why or why not? Cite your evidence--you also may use DLESE and/or google to help you with your answer.

3B. Sketch the three examples of Ediacaran organisms that we have in lab, give their names (don't forget to underline and/or *italicize* the genus name), and give the scale.

i. What is the evidence that these organisms are multicellular? Should they be included in the Domain Eukaryota? Why or why not?

ii. As for being included in the Kingdom Animalia, do you see any indication of a mouth, anus, or muscles/tissues preserved on these organisms? Explain.

iii. Based on the evidence that you just collected already for this work station, are these organisms precursors to the major groups of invertebrates we have today (i.e., Phylum Cnidaria, Phylum Annelida, Phylum Arthropoda? Phylum Echinodermata?) or, might they be body plans that no longer exit? <u>Please use evidence and provide several theories to for your answer.</u>

IV. <u>Work Station No. 4</u>. Near the end of the Proterozoic, a great abundance of trace fossils (also called ichnofossils) appeared. While some of these fossils in this workcenter are not from the Proterozoic, they are indicative of some of the forms that were present at that time. Today, we will not focus on the types of trace fossils , but rather, what the implications are of having these trace fossils in such ancient rocks.

4A. Examine the fossiliferous rocks at this work station: are they trace fossils? Why or why not?

4B. If the rocks contain trace fossils, what trace fossils do you find? Sketch the types that you see (don't forget scale and provide a sedimentary analysis of the rock they are found in).

4C. Lastly, what is the evolutionary significance of these trace fossils if they are representative of late Proterozoic rocks? Think about this question in relation to body plans of organisms.

V. <u>Work Station No. 5</u>: Now, can you answer the questions posed at the beginning of the lab? Bring all your data together starting with Work Station 1 and continuing through Work Station 4 as evidence to support your answer.

LAB 5: Skeletons and the Perils of Preservations

Readings: Chap. 1; DLESE; Galileo; and/or Google/ other text information

George Cuvier, a most noted French vertebrate palentologist in the late 1700's. was the director of the Paris Natural History Museum. He reluctantly hired J. Baptiste Lamarck to catalog the "unmentionables" or "untouchables" in natural history, that is the group called the "*vermes*". At that time, the group *"vermes"* included just about everything that no one could catalog. As it happened, Lamarck was an exceptionally keen observer and tireless worker, the hallmarks of a good scientist. Lamarck was able to catalog (i.e. put into phyla) almost everything Cuvier deemed to push his way. In fact, while Cuvier was known as the "Father of <u>Vertbrate</u> Paleontolgy; Vertebrate Anatomy", Lamarck became known as the "Father of <u>Invertebrate</u> Zoology/ Paleontolgy."

One day, Lamarck was given an especially difficult task of determining the Phylum (or other grouping) of organism and the preservational state. Lamarck was given 30 samples to analyze by Cuvier. First, can you help Lamarck sort these bauplane (body plan) groups into <u>invertebrate phyla</u> (animals without backbones) or other groups (e.g. plants, Phylum Chordata, or other category – perhaps carbonate sedimentary rocks such as ooids). Second, for the groups you organize, figure out the preservational states present for that group and, if applicable, the sedimentary rock that the fossil is preserved in. Thus you need to develop a data table with the important data to collect (remember Lab 1!) Append this data table to the final report (the data table and/or illustrations need not be typed or redrawn)

In the end, <u>you will write a report,</u> to Cuvier covering just five of the major bauplane that you are most familiar with from this lab. For each of the five major bauplane, you will: 1) name the phylum (if applicable); 2) provide the distinguishing characteristics of that phylum that you used (be careful here, as you use only the characteristics available in the fossil record) ; 3) list the sample numbers that go with this phylum and why; 4) provide a description of the types of sedimentary rocks the specimens per phyla are consistently preserved in; and finally, 5) describe the range of preservational states and the most common preservation mode (state) the phyla are found in.

This lab is due next Tuesday, by 5pm, October 5, so we can grade it and get it back to you by Thursday Oct. 7. This is so you can use it to study for Exam 1.

Appendix J

Student Case Reports

Case Study File – Jackson [abbreviated herein by JF]

Personal Data

- 20 year old male
- 3rd year student
- Geology major, Forestry minor
- 7 credit hours of geology (Geol 1121, Geol 1260)
- Only enrolled in GEOL 4010 during course of study
- Other science background: has taken biology, chemistry and astronomy

LAB REPORT ANALYSES

LAB 1:

1. Do these rock samples contain any information in regard to plate tectonics – that is, do the rocks indicate the assembly of western North America in any way? Given the suite of rocks, would you conclude that western North America was an active or passive margin?
2. Additionally, do the rocks indicate any major environments that occurred in these areas in the past?
3. For selected rock types found in this lab, how are they related to the rock cycle?

GIVE PRIORITY TO EVIDENCE

- *In what ways did students plan to organize and track data collection?*

Evidence:

- no evidence of *planning* to organize and track data collection

- *Did students follow procedures? Were they thorough, systematic and precise in collecting and describing data?*

Evidence:

- Yes, followed procedures as observed in class, but no mention of those procedures in final lab report. No indication of methods used to formulate explanations about rock types or depositional environments.

- *Did students create different representations of data through charts, graphs, or summary tables?*

Evidence:

- He included a basic table outline the sample number, name of sample and rock type.
- He also included a table that indicated the chronological order of the samples (from youngest to oldest)

FORMULATE EXPLANATIONS FROM EVIDENCE

- *What data did students use to formulate explanations and how did they use it?*

Evidence:

- it is unclear from Jf's lab report what data he used to formulate his explanations, as he does not make mention of any evidence in his essay or how he gathered or used that evidence to reach his conclusions

- *Were students accurate in interpreting the data?*

Evidence:

- Jf demonstrated a high degree of accuracy determining the rock type and name, however he neglected to include information regarding his evidence for determining this information, as well as the depositional environment, thus he lost a significant number of points from his final lab report grade

- His essay provided a general response to the inquiry question – but he did not support his interpretations with explicit reference to his data.

EVALUATE EXPLANATIONS IN LIGHT OF ALTERNATIVES

- *What resources did students use?*

Evidence:

- textbook?

COMMUNICATE AND JUSTIFY PROPOSED EXPLANATIONS

- *How did students present their conclusions?*

Evidence:

- Jf presented his findings in a handwritten report, in which he included a basic table outline the sample number, name of sample and rock type. He also included a table that indicated the chronological order of the samples (from youngest to oldest). He also attached his data collection notes.

- *Did they use the data to justify their conclusion?*

Evidence:

- His essay provided a general response to the inquiry question – but he did not support his interpretations with explicit reference to his data.

LAB 2: One of the most pressing questions in paleobiology and astrobiology today concerns the criteria by which we recognize life on earth. Can criteria for life on Earth be directly used to recognize life on other planets?

1. Develop biogenicity criteria for recognizing life forms in ancient Archean Eon rocks. What types of information would you be looking for and how would you analyze it?
2. Can the criteria you develop for Archean rocks be used to recognize life on other planets?

GIVE PRIORITY TO EVIDENCE

- *In what ways did students plan to organize and track data collection?*

Evidence:

- No evidence of *planning*
- Students were directed in lab directions to proceed from station to station (they had to begin at station 1, but from there could complete the other stations in any order)

- *Did students follow procedures? Were they thorough, systematic and precise in collecting and describing data?*

Evidence:

- This lab was set up in work stations so students proceeded through workstations in an orderly fashion
- Jf while collaborating with other students examined/sketched the hand & slide samples and discussed and reached conclusions accordingly

- *Did students create different representations of data through charts, graphs, or summary tables?*

Evidence:

- no charts of graphs created for this lab report

FORMULATE EXPLANATIONS FROM EVIDENCE

- *What data did students use to formulate explanations and how did they use it?*

Evidence:

- Jf developed biogenicity critieria for recognizing life forms with group (Jn, Krs, M) and then used these criteria to formulate conclusions regarding the samples he examined

- *Were students accurate in interpreting the data?*

Evidence:

- Jf demonstrated a high degree of accuracy in identifying the samples (biogenetic or not) missing only 1 sample
- Jf also demonstrated a high degree of accuracy interpreting the data – however he lost points for not given enough details or specifics in his explanations
- Jf received a grade of 95% on this lab – much improved from his performance on the first lab assignment

EVALUATE EXPLANATIONS IN LIGHT OF ALTERNATIVES

- *What resources did students use?*

Evidence:

- Students were required to use DLESE for this assignment

COMMUNICATE AND JUSTIFY PROPOSED EXPLANATIONS

- *How did students present their conclusions?*

Evidence:

- Jf presented his findings in a typed report, summarizing his findings to the specific questions for each workstation in an essay format. He also attached his data collection notes to the back of the report.

- *Did they use the data to justify their conclusion?*

Evidence:

- Yes, Jf explicitly refers to evidence collected from the samples to support and justify his conclusions throughout his report

LAB 3: A major question in paleobiology is how did we get so many organisms on earth, with the incredible breadth of diversity.

1. What are eukaryotes?
2. How and when did they originate?
3. What are the first eukaryotes in the fossil record from the Proterozoic Eon, and how are they recognized (criteria)?

GIVE PRIORITY TO EVIDENCE

- *In what ways did students plan to organize and track data collection?*

Evidence:

- No evidence of *planning*
- Students were directed in lab directions to proceed from station to station (they had to begin at station 1, but from there could complete the other stations in any order)

- *Did students follow procedures? Were they thorough, systematic and precise in collecting and describing data?*

Evidence:

- Jf states clearly what procedures were used at each workstation; see lab report for further details
- This lab was set up in work stations so students proceeded through workstations in an orderly fashion

- Jf examined/sketched the micrograph samples

- *Did students create different representations of data through charts, graphs, or summary tables?*

Evidence:

- Jf did not create any charts, graphs or summary tables

FORMULATE EXPLANATIONS FROM EVIDENCE

- *What data did students use to formulate explanations and how did they use it?*

Evidence:

- examined micrographs to determine which were eukaryotes and prokaryotes
  - primarily focused on elements of size and presence/non-presence of a nuclei
- Also examined plaster casts and molds to determine preservation modes and if they could be classified as eukaryotes
- Finally, examined rocks to determine if and what types of trace fossils were present and their evolutionary significance
-

- *Were students accurate in interpreting the data?*

Evidence:

- Jf gave a cursory overview of one experiment that provided evidence for the theory of endosymbiosis and did not describe Lynne Margulis' theory with any level of detail- therefore it is unclear from this report what level of understanding Jf attained of the theory
- Jf did not answer a number of questions from the lab assignment, thus he lost quite a large number of points – it is unclear as to whether he did not know the answers or just forgot to complete the questions
- Jf received an overall grade of 55% on this lab report

EVALUATE EXPLANATIONS IN LIGHT OF ALTERNATIVES

- *What resources did students use?*

Evidence:

- it is unclear whether any resources were used to complete this lab

COMMUNICATE AND JUSTIFY PROPOSED EXPLANATIONS

- *How did students present their conclusions?*

Evidence:

- Jf presented his findings in a typed lab report. Unlike the other students, Jf used a traditional lab-report style, in which he had an introduction, methods, results, and discussion section
- Jf also attached his data collection notes to the report

- *Did they use the data to justify their conclusion?*

Evidence:

- Yes, Jf used his data to justify his conclusions

LAB 5: Skeletons and the Perils of Preservations – One day, Lamarck was given an especially difficult task of determining the Phylum (or other grouping) of organism and the preservational state. Lamarck was given 30 samples to analyze by Cuvier. First, can you help Lamarck sort these bauplane (body plan) groups into <u>invertebrate phyla</u> (animals without backbones) or other groups (e.g. plants, Phylum Chordata, or other category – perhaps carbonate sedimentary rocks such as ooids). Second, for the groups you organize, figure out the preservational states present for that group and, if applicable, the sedimentary rock that the fossil is preserved in.

GIVE PRIORITY TO EVIDENCE

- *In what ways did students plan to organize and track data collection?*

Evidence:

- No evidence that of *planning*

- *Did students follow procedures? Were they thorough, systematic and precise in collecting and describing data?*

Evidence:

- No evidence of procedures followed to gather data in this lab report

- *Did students create different representations of data through charts, graphs, or summary tables?*

Evidence:

- Jf did not create a chart of graph or table for this lab report

FORMULATE EXPLANATIONS FROM EVIDENCE

- *What data did students use to formulate explanations and how did they use it?*

Evidence:

- Used observations about the rock to categorize into phyla and determine preservation mode

- *Were students accurate in interpreting the data?*

Evidence:

- Jf demonstrated a high level accuracy interpreting the data
- Jf received a score of 85% on this lab report

EVALUATE EXPLANATIONS IN LIGHT OF ALTERNATIVES

- *What resources did students use?*

Evidence:

- there is no indication of other resources used to complete this lab report

COMMUNICATE AND JUSTIFY PROPOSED EXPLANATIONS

- *How did students present their conclusions?*

Evidence:

- Jf presented his conclusions in a typed report, written in an essay style. He also appended his data collection notes to his lab report

- *Did they use the data to justify their conclusion?*

Evidence:

- Throughout the report Jf made reference to his data to support his conclusions

Case Study File – Jake [Abbreviated herein by JN]

Personal Data

- 22 year old male
- 5th year student (transferred from another school)
- Geology major, no minor
- Has 7 credit hours of geology (Geol 1250, 1260)
- Currently enrolled in Geol 3010 and 3020 as well as Geol 4950 (Journal Club)
- Other science background: Has taken biology, chemistry and physics

LAB REPORT ANALYSES

LAB 1:

a. Do these rock samples contain any information in regard to plate tectonics – that is, do the rocks indicate the assembly of western North America in any way? Given the suite of rocks, would you conclude that western North America was an active or passive margin?
b. Additionally, do the rocks indicate any major environments that occurred in these areas in the past?
c. For selected rock types found in this lab, how are they related to the rock cycle?

GIVE PRIORITY TO EVIDENCE

- *In what ways did students plan to organize and track data collection?*

Evidence:

- no evidence of *planning* to organize and track data collectio

- *Did students follow procedures? Were they thorough, systematic and precise in collecting and describing data?*

Evidence:

- Yes. As observed in class and as described in his lab report, Jn, followed a systematic procedure for collecting and describing data (see lab report page 1-2)
    - worked in a group with M, Jf & Krs to collect data

- *Did students create different representations of data through charts, graphs, or summary tables?*

Evidence:

- Yes. Jn created a detailed table outlining the place, time period, rock type, rock evidence and details, rock specifics, and possible rock facies/environments, for each of the samples from the 2 sets of data (S1-15/ T1-15)

FORMULATE EXPLANATIONS FROM EVIDENCE

- *What data did students use to formulate explanations and how did they use it?*

Evidence:

- As indicated in the lab report Jn used the following information in the following ways to formulate explanations: rock locality – to understand the context of the rock's formation with in the group of 30; rock type – used to help identify the environment they were created in; time period rock was created in – combined with all other facts this would help determine the events and processes that created the rocks

- *Were students accurate in interpreting the data?*

Evidence:

- Jn had a high level of accuracy in determining both the rock type and environment in which it was formed.
- He also received a perfect score for his interpretation of this data with regards to the major questions of the lab.

- He received a total score of 92% on the lab report, one of the highest scores.

EVALUATE EXPLANATIONS IN LIGHT OF ALTERNATIVES

- *What resources did students use?*

Evidence:

- In his interview 2, Jn indicated uses the textbook as a resource for this lab

COMMUNICATE AND JUSTIFY PROPOSED EXPLANATIONS

- *How did students present their conclusions?*

Evidence:

- Jn presented his findings by writing a typed lab report, using an essay format to present his findings. He attached a table outlining his data findings and conclusions. He did not attach his data collection notes.

- *Did they use the data to justify their conclusion?*

Evidence:

- Yes, see attached data table.

LAB 2: One of the most pressing questions in paleobiology and astrobiology today concerns the criteria by which we recognize life on earth. Can criteria for life on Earth be directly used to recognize life on other planets?

3. Develop biogenicity criteria for recognizing life forms in ancient Archean Eon rocks. What types of information would you be looking for and how would you analyze it?
4. Can the criteria you develop for Archean rocks be used to recognize life on other planets?

GIVE PRIORITY TO EVIDENCE

- *In what ways did students plan to organize and track data collection?*

Evidence:

- No evidence of *planning*
- Students were directed in lab directions to proceed from station to station (they had to begin at station 1, but from there could complete the other stations in any order)

- *Did students follow procedures? Were they thorough, systematic and precise in collecting and describing data?*

Evidence:

- This lab was set up in work stations so students proceeded through workstations in an orderly fashion
- Jn, while collaborating with other students examined/sketched the hand & slide samples and discussed and reached conclusions accordingly

- *Did students create different representations of data through charts, graphs, or summary tables?*

Evidence:

- Jn did not create and charts, tables or graphs for this lab

FORMULATE EXPLANATIONS FROM EVIDENCE

- *What data did students use to formulate explanations and how did they use it?*

Evidence:

- Jn developed biogenicity critieria for recognizing life forms with group (Jf, Krs, M) based on lecture material and with a resource found on DLESE(as stated in his lab report) and then used these criteria to formulate conclusions regarding the samples he examined

- *Were students accurate in interpreting the data?*

Evidence:

- Jn demonstrated a high degree of accuracy of for identifying the samples, only misidentifying one sample,
- However Jn lost points for imprecise descriptions of some samples
- In addition, Jn did not directly answer the inquiry question (did not interpret the data) and thus did not receive credit for this portion of the assignment
- Jn received a grade of 85% on this lab

EVALUATE EXPLANATIONS IN LIGHT OF ALTERNATIVES

- *What resources did students use?*

Evidence:

- Students were required to use DLESE for this assignment

COMMUNICATE AND JUSTIFY PROPOSED EXPLANATIONS

- *How did students present their conclusions?*

Evidence:

- Jn presented his findings in a typed report, summarizing his findings to the specific questions for each workstation in an essay format. He also attached his data collection notes to the back of the report.

- *Did they use the data to justify their conclusion?*

Evidence:

- Yes, Jn explicitly refers to evidence collected from the samples to support and justify his conclusions throughout his report

LAB 3: A major question in paleobiology is how did we get so many organisms on earth, with the incredible breadth of diversity.

4. What are eukaryotes?
5. How and when did they originate?
6. What are the first eukaryotes in the fossil record from the Proterozoic Eon, and how are they recognized (criteria)?

GIVE PRIORITY TO EVIDENCE

- *In what ways did students plan to organize and track data collection?*

Evidence:

- No evidence of *planning*
- Students were directed in lab directions to proceed from station to station (they had to begin at station 1, but from there could complete the other stations in any order)

- *Did students follow procedures? Were they thorough, systematic and precise in collecting and describing data?*

Evidence:

- This lab was set up in work stations so students proceeded through workstations in an orderly fashion
- Jn, examined/sketched the micrgraph samples

- *Did students create different representations of data through charts, graphs, or summary tables?*

Evidence:

- Jn did not create any charts, graphs or summary tables for this lab

FORMULATE EXPLANATIONS FROM EVIDENCE

- *What data did students use to formulate explanations and how did they use it?*

Evidence:

- examined micrographs to determine which were eukaryotes and prokaryotes
  - primarily focused on elements of size and presence/non-presence of a nuclei
- Also examined plaster casts and molds to determine preservation modes and if they could be classified as eukaryotes
- Finally, examined rocks to determine if and what types of trace fossils were present and their evolutionary significance

- *Were students accurate in interpreting the data?*

Evidence:

- Jn demonstrated a high degree of accuracy in interpreting the data, only misidentifying one sample as eukaryote (when really a prokaryote) but able to put samples in order of complexity.
- Jn also misidentified a few trace fossils
- His interpretation of the data was excellent
- He received a score of 93% on this lab report

EVALUATE EXPLANATIONS IN LIGHT OF ALTERNATIVES

- *What resources did students use?*

Evidence:

- no indication that other resources used to complete this lab

COMMUNICATE AND JUSTIFY PROPOSED EXPLANATIONS

- *How did students present their conclusions?*

Evidence:

- Jn presented his findings in a typed report, in essay form to address all the questions of the lab
- He attached his data collection notes to the back of the lab report

- *Did they use the data to justify their conclusion?*

Evidence:

- Yes, Jn used his data to support his conclusions throughout his report

LAB 5: Skeletons and the Perils of Preservations – One day, Lamarck was given an especially difficult task of determining the Phylum (or other grouping) of organism and the preservational state. Lamarck was given 30 samples to analyze by Cuvier. First, can you help Lamarck sort these bauplane (body plan) groups into <u>invertebrate phyla</u> (animals without backbones) or other groups (e.g. plants, Phylum Chordata, or other category – perhaps carbonate sedimentary rocks such as ooids). Second, for the groups you organize, figure out the preservational states present for that group and, if applicable, the sedimentary rock that the fossil is preserved in.

GIVE PRIORITY TO EVIDENCE

- *In what ways did students plan to organize and track data collection?*

Evidence:

- no evidence of *planning*

- *Did students follow procedures? Were they thorough, systematic and precise in collecting and describing data?*

Evidence:

- Yes, as indicated in his report Jn first performed a cursory examination of the samples, sorting them by their physical characteristics, then performed a more thorough examination of the samples, testing their composition using HCL

- *Did students create different representations of data through charts, graphs, or summary tables?*

Evidence:

- Jn created a chart to organize his data that included the sample number, the phyla, the preservational state, the name of the organism or miscellaneous characteristics, and the sedimentary structure that each fossil is in

FORMULATE EXPLANATIONS FROM EVIDENCE

- *What data did students use to formulate explanations and how did they use it?*

Evidence:

- As indicated in the lab report, Krs used the data she noted from the samples including phylum, mode of preservation, type of sedimentary rock specimen preserved in, etc.
- Used observations about the rock to categorize into phyla and determine preservation mode

- *Were students accurate in interpreting the data?*

Evidence:

- Jn demonstrated a high degree of accuracy in interpreting the data
- Jn received an overall score of 85% on the lab report

EVALUATE EXPLANATIONS IN LIGHT OF ALTERNATIVES

- *What resources did students use?*

Evidence:

- As indicated in his report Jn used his textbook and the paleonotes provided to help him formulate conclusions

COMMUNICATE AND JUSTIFY PROPOSED EXPLANATIONS

- *How did students present their conclusions?*

Evidence:

- Jn presented his conclusions in a typed report written essay style (possibly as Lamarck?)

- *Did they use the data to justify their conclusion?*

Evidence:

- Yes, Jn used the data to justify his conclusions throughout his report

Case Study File – Karen [Abbreviated herein by KRS]

Personal Data

- 20 year old female
- 3rd year student
- Geology major, no minor
- 12 credit hours of geology background (Geol 1250, Geol 1260, Geol 4950 [Journal club – not really a course – listen to guest speakers], Geol X – internship course with specific prof)
- Currently enrolled in 3 other geology courses while taking geol 4010 (Geol 3010, Geol 3020, and Geol 4220) as well as Geol 4950 [Journal club]
- Other science background: has taken chemistry and astronomy – no biology

LAB REPORT ANALYSES

LAB 1:

5. Do these rock samples contain any information in regard to plate tectonics – that is, do the rocks indicate the assembly of western North America in any way? Given the suite of rocks, would you conclude that western North America was an active or passive margin?
6. Additionally, do the rocks indicate any major environments that occurred in these areas in the past?
7. For selected rock types found in this lab, how are they related to the rock cycle?

GIVE PRIORITY TO EVIDENCE

- *In what ways did students plan to organize and track data collection?*

Evidence:

- worked in a group for this lab with Jf, M & Jn.
- No evidence of how she *planned* to organize and track data collection
- Attached to lab report are her notes from her data collection which appear organized by sample, and fairly detailed and thorough

- *Did students follow procedures? Were they thorough, systematic and precise in collecting and describing data?*

Evidence:

- yes, as observed she moved with group from sample to sample, discussing and taking notes on specific details and features of the sample
- yes, provides a thorough and detailed description of her data collection procedures in lab report (see page 1 of lab report); description of data is supplied in her data collection notes as well as a table she created with organizes the samples from youngest to oldest

- *Did students create different representations of data through charts, graphs, or summary tables?*

Evidence:

- yes, she created and attached a table to her lab report organizing the 2 sets of samples (S1-15/T1-15) from youngest to oldest

FORMULATE EXPLANATIONS FROM EVIDENCE

- *What data did students use to formulate explanations and how did they use it?*

Evidence:

- As indicated in the lab report she used the rock samples (S1-15/T1-15) to gather information regarding the sample number, location, characteristics, rock type, name, environment of deposition
- As indicated in the lab report she used the geological map provided in class to gather the rock samples locations and time periods

- *Were students accurate in interpreting the data?*

Evidence:

- She demonstrated a high degree of accuracy in identifying the rock type as well as the depositional environment of the rock
- She scored perfect on her interpretation of the data (the essay portion of the lab report in which she was required to answer the major questions for the lab)
- Overall scored 92% on the lab – one of the highest grades

EVALUATE EXPLANATIONS IN LIGHT OF ALTERNATIVES

- *What resources did students use?*

Evidence:
- as indicated in interview 2, she used her textbook as a resource for this lab

COMMUNICATE AND JUSTIFY PROPOSED EXPLANATIONS

- *How did students present their conclusions?*

Evidence:

- she presented her findings in a typed lab report, writing a general essay to address the inquiry questions, and attaching her data collection notes, and her tables showing her organization of her data (organizing the samples for youngest to oldest)

- *Did they use the data to justify their conclusion?*

Evidence:

- yes, throughout her essay, she reported which samples were used to support her conclusions

LAB 2: One of the most pressing questions in paleobiology and astrobiology today concerns the criteria by which we recognize life on earth. Can criteria for life on Earth be directly used to recognize life on other planets?

5. Develop biogenicity criteria for recognizing life forms in ancient Archean Eon rocks. What types of information would you be looking for and how would you analyze it?
6. Can the criteria you develop for Archean rocks be used to recognize life on other planets?

GIVE PRIORITY TO EVIDENCE

- *In what ways did students plan to organize and track data collection?*

Evidence:

- no evidence of *planning*
- Students were directed in lab directions to proceed from station to station (they had to begin at station 1, but from there could complete the other stations in any order)

- *Did students follow procedures? Were they thorough, systematic and precise in collecting and describing data?*

Evidence:

- This lab was set up in work stations so students proceeded through workstations in an orderly fashion
- Krs while collaborating with other students examined/sketched the hand & slide samples and discussed and reached conclusions accordingly

- *Did students create different representations of data through charts, graphs, or summary tables?*

Evidence:

- Krs inserted a table of her groups criteria for biogenicity
- Krs also inserted figures of her sketches and of pictures that she found on the Web to support her findings

FORMULATE EXPLANATIONS FROM EVIDENCE

- *What data did students use to formulate explanations and how did they use it?*

Evidence:

- Krs developed biogenicity critieria for recognizing life forms with group (Jn, Krs, M) and then used these criteria to formulate conclusions regarding the samples she examined

- *Were students accurate in interpreting the data?*

Evidence:

- Krs demonstrated a high degree of accuracy in identifying the samples, misidentifying only 1 sample
- Krs also demonstrated a high degree of accuracy in interpreting her data to answer the inquiry questions, receiving full credit
- Krs received the highest grade on the lab report, 100%

EVALUATE EXPLANATIONS IN LIGHT OF ALTERNATIVES

- *What resources did students use?*

Evidence:

- Students were required to use DLESE for this lab
- Krs also found pictures at 2 other web resources as cited in her lab report (htpp://www.nigral.net/life_seek.html) and (http://www.lpi.usra.edu/education/EPO/yellowstone2002/workshop/stromatolite)

COMMUNICATE AND JUSTIFY PROPOSED EXPLANATIONS

- *How did students present their conclusions?*

Evidence:

- Krs presented her findings in a typed report, summarizing her findings to the specific questions for each workstation in an essay format. She also attached her data collection notes to the back of the report.

- *Did they use the data to justify their conclusion?*

Evidence:

- Yes, Krs explicitly refers to evidence collected from the samples to support and justify her conclusions throughout her report

LAB 3: A major question in paleobiology is how did we get so many organisms on earth, with the incredible breadth of diversity.

7. What are eukaryotes?
8. How and when did they originate?
9. What are the first eukaryotes in the fossil record from the Proterozoic Eon, and how are they recognized (criteria)?

GIVE PRIORITY TO EVIDENCE

- *In what ways did students plan to organize and track data collection?*

Evidence:

- No evidence of *planning*
- Students were directed in lab directions to proceed from station to station (they had to begin at station 1, but from there could complete the other stations in any order)

- *Did students follow procedures? Were they thorough, systematic and precise in collecting and describing data?*

Evidence:

- This lab was set up in work stations so students proceeded through workstations in an orderly fashion
- Krs, examined/sketched the micrgraph samples

- *Did students create different representations of data through charts, graphs, or summary tables?*

Evidence:

- Krs included some figures (from the web, and her own sketches) to illustrate the concepts in her explanations

FORMULATE EXPLANATIONS FROM EVIDENCE

- *What data did students use to formulate explanations and how did they use it?*

Evidence:

- examined micrographs to determine which were eukaryotes and prokaryotes
    - primarily focused on elements of size and presence/non-presence of a nuclei
- Also examined plaster casts and molds to determine preservation modes and if they could be classified as eukaryotes
- Finally, examined rocks to determine if and what types of trace fossils were present and their evolutionary significance

- *Were students accurate in interpreting the data?*

Evidence:

- Krs appeared to have some confusion about the difference between eukaryotes and prokaryotes
- Krs also demonstrated some confusion related to the concept of endosymbiosis
- Note: Krs had not previously taken any university-level biology courses
- Krs also demonstrated some confusion related to the dates of origin of eukaryotic organisms
- Krs received a grade of 61% on this lab

EVALUATE EXPLANATIONS IN LIGHT OF ALTERNATIVES

- *What resources did students use?*

Evidence:

- Krs sought out additional information, citing 5 references at the end of her report
    - Dott, R. H. & Prothero, D. Evolution of the Earth, Seventh Edition [NOTE: Previous course textbook]
    - Prothero, D. Bringing fossils to life: An introduction to paelobiology, Second Edition - [NOTE: Course textbook]
    - http://www.ucmp.berkeley.edu/vendian/critters.html
    - http://www.mansfield.ohio-state.edu/sabedon/campb107.htm#eukaryote
    - http://evolution.berkely.edu/evosite/resources/readings_dawson3.shtml

COMMUNICATE AND JUSTIFY PROPOSED EXPLANATIONS

- *How did students present their conclusions?*

Evidence:

- Krs presented her findings in a typed report, in essay form to address all the questions of the lab
- She attached her data collection notes to the back of the lab report

- *Did they use the data to justify their conclusion?*

Evidence:

- Yes, Krs used her data to support her conclusions throughout the report

LAB 5: Skeletons and the Perils of Preservations – One day, Lamarck was given an especially difficult task of determining the Phylum (or other grouping) of organism and the preservational state. Lamarck was given 30 samples to analyze by Cuvier. First, can you help Lamarck sort these bauplane (body plan) groups into invertebrate phyla (animals without backbones) or other groups (e.g. plants, Phylum Chordata, or other category – perhaps carbonate sedimentary rocks such as ooids). Second, for the groups you organize, figure out the preservational states present for that group and, if applicable, the sedimentary rock that the fossil is preserved in.

GIVE PRIORITY TO EVIDENCE

- *In what ways did students plan to organize and track data collection?*

Evidence:

  - no evidence of *planning*

- *Did students follow procedures? Were they thorough, systematic and precise in collecting and describing data?*

Evidence:

  - Yes, as stated in her lab report Krs examined each sample noting the sample number, phylum, mode of preservation, type of sedimentary rock, etc

- *Did students create different representations of data through charts, graphs, or summary tables?*

Evidence:

  - Yes, as stated in her lab report Krs compiled her data in a table from oldest to youngest, categorizing the samples by Kingdom – within the table each sample was represented by phylum name, preservation method, and rock type

FORMULATE EXPLANATIONS FROM EVIDENCE

- *What data did students use to formulate explanations and how did they use it?*

Evidence:

  - As indicated in the lab report, Krs used the data she noted from the samples including phylum, mode of preservation, type of sedimentary rock specimen preserved in, etc.
  - Used observations about the rock to categorize into phyla and determine preservation mode

- *Were students accurate in interpreting the data?*

Evidence:

  - Krs demonstrated a high degree of accuracy in interpreting that data
  - Krs receive a score of 97% on her lab report

EVALUATE EXPLANATIONS IN LIGHT OF ALTERNATIVES

- *What resources did students use?*

Evidence:

  - there is no indication that other resources were used in this lab

COMMUNICATE AND JUSTIFY PROPOSED EXPLANATIONS

- *How did students present their conclusions?*

Evidence:

  - Krs presented her conclusions in a typed report, using a traditional lab-report style which included an introduction, methods, and results (no discussion or conclusion)
  - NOTE: Students were given a handout describing how to write up their lab reports using this style

- *Did they use the data to justify their conclusion?*

Evidence: