From Evidence to Explanations: Engaging undergraduate geology students in inquiry

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Abstract: This paper reports the synthesis of six case studies of students' engagement in inquiry-based learning activities in an undergraduate geology course. Details of how students engaged in the scientific inquiry practices of *formulating explanations from evidence,* and *communicating and justifying proposed explanations* are presented. Data for this study included classroom observations and archival data (i.e., student work samples) collected during a semester-long investigation. The results suggest that students were able to appropriate these inquiry practices with varying degrees of success, however, it was not without its challenges. A detailed discussion of the ways in which students were successful, and where they had challenges engaging in these inquiry practices is presented, with the goal of helping guide practitioners and researchers in creating learning environments that can take full advantage of the pedagogical strategy of inquiry-based learning.

Background

> *[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.*
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> *(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 that emphasizes the human elements (e.g., successes, failures and emotional dispositions) that are associated with engaging in science as inquiry (Yore, Florence, Pearson, & Weaver, 2002). This is in direct opposition to the 'science-as-a-noun' perspective, which stresses textbook knowledge, lists and procedures about scientific processes. Geoscience education 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 of processes. These recommendations are based on the *National Science Education Standards* (NSES) (National Research Council, 1996) and the *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993) (Barstow & Geary, 2002).

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). There are a number of undergraduate geoscience educators that have utilized inquiry-based teaching methods in their courses (Keller, Allen-King, & O'Brien, 2000), but integrating inquiry-based teaching methods in undergraduate science instruction may be even more difficult than integrating inquiry methods into K-12 learning environments. Inquiry as a teaching methodology and learning experience emphasizes providing students with opportunities to engage in activities similar to those required for real-world scientific research. When learners are engaged in inquiry-based learning environments they should (National Research Council, 2000): (a) be engaged in scientifically oriented questions; (b) give priority to evidence, allowing them to develop and evaluate explanations that address scientifically oriented questions; (c) formulate explanations from evidence to address scientifically oriented questions; (d) evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding; and (e) communicate and justify their proposed explanations. These five elements are essential characteristics of an inquiry-based learning environment.

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) and have 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. While these three noteworthy studies provide much needed insight into how students at the middle and high school level are engaged in inquiry, and what they 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 six case studies of students' engagement in inquiry-based learning activities in an undergraduate geology laboratory that utilized teaching and learning strategies supportive of the recommendations found in *Blueprint for Change*. Thus, a goal of this research is to describe realistically what college students do, and where they experience challenges, when engaged in the inquiry practices of *formulating explanations* and *communicating and justifying their findings*. Studies such as this 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.

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. Although data was collected documenting how students engaged in the various inquiry practices outlined in the NSES, of primary interest here is how students appropriated and engaged in the scientific inquiry practices of *formulating explanations from evidence* and *communicating and justifying proposed explanations*. The inquiry practice of formulating explanations is of particular interest because research suggests that although students are able to appropriate the inquiry practices of designing and carrying out simple investigations, they often state conclusions that are inconsistent with or are not warranted by their data (Kanari & Millar, 2004). The ability to draw and justify conclusions, is an inquiry practice that may be especially difficult for students to appropriate as it requires sophisticated thinking with which students from middle school through graduate school may be expected to have difficulty (Krajcik et al., 1998). Thus, the following research questions were addressed:

1. How do students appropriate and engage in the inquiry practice of *formulating explanations from evidence* in an inquiry-based undergraduate geology laboratory?
2. How do students appropriate and engage in the inquiry practice of *communicating and justifying proposed explanations* in an inquiry-based undergraduate geology laboratory?

Research Design and Methods

Research Design

The analysis described in this paper stems from a larger interpretive qualitative study that utilized a layered case-study approach which 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 here was the individual student.

Context and Setting

This research was conducted in an upper-level undergraduate geology course consisting of 2 hours of lecture and 3 hours of lab per week, taught at a large research university located in the southeastern USA. The author worked collaboratively with the course instructor to design the inquiry-based activities used in the laboratory component of the course.

Course Description

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 while conducting scientific investigations. In addition, students were encouraged to access dynamic and static resources available in a digital library for earth sciences (DLESE – www.dlese.org).

The inquiry tasks were structured according to guidelines for creating inquiry-based learning environments suggested in the NSES. 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. 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 (e.g. developing alternative explanations, interpreting data, selecting among alternative hypotheses, etc.) (Clough, 2002). The following is an example of an inquiry task from Inquiry Assignment 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 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?*

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. One participant was excluded from the final analysis presented here due to an insufficient number of work samples. Participants have all been given pseudonym names.

Data Collection & Sources

For the analysis reported in this paper, student work samples were collected and used as the primary source of data. Of the eight inquiry assignments that students completed throughout the course, four inquiry assignments were chosen for analysis here. In addition, both the midterm and final exam (which were also inquiry-based) were analyzed to help provide a rich picture of students' appropriation of the inquiry practices.

Data Analysis

A deductive analysis (Patton, 2002) approach, in which several questions that related to the inquiry practices of interest (formulating explanations, and justifying proposed explanations), guided analysis of students' inquiry assignments and exams (See Table 1). These analysis questions were developed based on research conducted by Krajcik et al. (1998).

Table 1. Inquiry Practices, Analysis Questions, and Data Sources

Inquiry Process	Analysis questions	Data Sources
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?	Inquiry assignments (lab reports) Midterm exam (in class) Final exam (take home)
Communicate and justify proposed explanations	How did students present their conclusions? Did they use the data to justify their conclusions?	Inquiry assignments (lab reports) Midterm exam (in class) Final exam (take home)

Next, cases were created for each student, consisting of a summary of each student's proficiency with the inquiry practices of *formulating explanations from evidence* and *communicating and justifying proposed explanations*. Students performance on inquiry assignments inquiry-based exams were characterized as demonstrating a level of 'high proficiency', 'moderate proficiency', or 'low proficiency' for each inquiry practice. Proficiency level was determined based on the characteristics described in Table 2.

Table 2. Proficiency Level Characteristics for Inquiry Practices

	Formulate explanations from evidence	Communicate and justify proposed explanations
High Proficiency	Accurate in interpretation of the data Provide detailed explanation of data used Demonstrate clear link of how data is connected to the presented explanation	Conclusions presented in a clear, concise manner Explicit reference made, and appropriate data used to support conclusions
Moderate Proficiency	Interpretation of data accurate the majority of the time Some explanation of data that is used Attempt to connect data to explanation but may be unclear or unspecific	Explicit reference made, and appropriate data used to support conclusions the majority of the time (but not always)
Low Proficiency	Incorrect interpretation of data majority of the time Little or no explanation of data that is used is provided Unclear how data collected is connected to explanation presented	Conclusions presented in convoluted manner Conclusions stated without reference to data collected

Results

Formulate explanations from evidence

As to be expected, students were able to appropriate this inquiry practice with varying levels of success. Table 3 presents a summary of each student's proficiency with the inquiry practice of *formulating explanations from evidence* for each inquiry assignment and exam. A more detailed description of students' proficiency with the inquiry practices is described below.

Table 3. Participants' Proficiency Formulating Explanations from Evidence

Assignments & Exams	Participants					
	Karen	Jake	Jackson	Melanie	Robin	Kyle
1	High	High	Low	Moderate	High	Moderate
2	High	High	High	Moderate	Low	Low
3	Low	High	Low	N/A	High	High
4	High	High	High	Moderate	High	High
Midterm	Moderate	High	Moderate	Moderate	High	Moderate
Final	High	Moderate	Moderate	Moderate	Low	Low

Amongst all the students, Karen, Jake and Robin demonstrated the highest levels of proficiency with this inquiry practice. Karen, Jake, and Robin, throughout the semester most consistently demonstrated their ability to formulate explanations based on evidence. In each of their lab reports, and on their exams, these students most often provided detailed explanations of the data they used, demonstrated how this data was connected to the explanation they put forth, and were highly accurate in their interpretation of their data. The following is a brief excerpt from Jake's 1st lab report, demonstrating his high level of proficiency with this inquiry practice:

> *…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 that they were created in. If the rock was sedimentary, we would see if the rock would react with HCL, as a reaction would tell us that there was carbonate sediments in the rock, which suggest a marine setting…*

In this excerpt, Jake describes the type of data collected (i.e., rock locality, type of rock) and how it can be used to formulate explanations. This excerpt from Jake's lab report is representative of the quality of Karen and Robin's work samples as well.

Jackson, Kyle and Melanie demonstrated moderate levels of proficiency in appropriating the inquiry practice of formulating explanations from evidence. Each student faced a different challenge in trying to appropriate this inquiry practice, resulting in varying levels of successful appropriation. For example, although in class Jackson was an active participant with his group and quite able to verbally connect the data he was collecting with his explanations, 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 the types of data that were obtained from the rock samples to warrant making such a claim. However, as the semester progressed Jackson made great strides in appropriating this inquiry practice, providing more details, and connecting his data to his explanations. Despite Jackson's propensity to neglect to supply detail, he was often accurate in his interpretation of the data (e.g., rock type, depositional environment, etc.).

Kyle's challenges to appropriating this inquiry practice were similar to those of Jackson's, in that Kyle often provided only a vague explanation of the data he used to generate his proposed explanation. Kyle also experienced some difficulty in correctly identifying and interpreting his data. Although he made great strides throughout the semester, Kyle's final exam performance was the lowest grade of the group, suggesting that he may not have adequately appropriated the inquiry practice after all.

Finally, Melanie demonstrated only moderate success in appropriating the practice of formulating explanations from evidence. Her performance was consistent throughout the semester, that is, she demonstrated very little improvement in her appropriation of the inquiry practice of formulating explanations from evidence. Of the three students characterized as demonstrating moderate proficiency with this inquiry practice, Melanie could be characterized as being the least proficient of the three. Melanie often only vaguely explained what data she used to reach her explanations, however her interpretation of the data was highly accurate the majority of the time. Below is an excerpt from Melanie's 1st lab report:

> *…Upon examination of [the samples from] both roads T and S, it was determined that both Arizona and New Mexico were part of an active margin…although there are some discrepancies in order which may be explained with further research, there is solid evidence of oceanic activities…*

In this excerpt Melanie briefly mentions that based on the data she collected from the samples representing rocks along roads T and S, she was able to make some conclusions regarding the geological past of the area. However, Melanie is not specific about what data she has collected that has allowed her to formulate such an explanation. This excerpt is representative of the amount of detail that Melanie would typically provide in her reports.

Communicate and justify proposed explanations

Overall, the students became increasingly competent with this inquiry practice, becoming more familiar with scientific discourse and methods for presenting their findings. With detailed feedback from the instructor, the students were able to appropriate this inquiry practice fairly well. A few students (i.e. Jake and Karen) were quite proficient with this practice almost from the outset of the course. For other students (i.e. Jackson) steady improvement in appropriating and engaging in this practice was documented. Unfortunately, for at least one student (i.e. Melanie) no change was documented in her ability to appropriate or engage in this inquiry practice. Table 4 presents a summary of each student's proficiency with the inquiry practice of *communicating and justifying proposed explanations* for each inquiry assignment and exam.

Table 4. Participants' Proficiency Communicating and Justifying Proposed Explanations

Assignments & Exams	Participants					
	Karen	Jake	Jackson	Melanie	Robin	Kyle
1	High	High	Low	Low	High	High
2	High	High	High	Low	Moderate	Moderate
3	High	High	Low	N/A	High	Moderate
4	High	High	High	Low	Moderate	High
Midterm	High	High	Moderate	Moderate	High	Moderate
Final	High	High	Moderate	Low	Low	Low

Discussion & Conclusions

Although, the students in this study occasionally made incorrect interpretations of their data, this did not seem to be the crux of their difficulty engaging in the inquiry practice of formulating explanations from data. 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.

The students in this study showed varying levels of competence communicating and justifying proposed explanations initially, but all made great strides by the end of the course. Difficulties with this inquiry practice 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, most students developed proficiency with this inquiry practice by the end of the course. Thus, appropriate modeling and feedback may be essential for students to successfully appropriate this practice.

This research has provided a much-needed description of how undergraduate science (geology) majors engage in inquiry practices 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). For the most part, these students appeared to truly engage in inquiry, 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. Studies such as this 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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