Assessing understanding of the nature of science and science self-efficacy in undergraduates involved in research in an introductory geology course

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Assessing understanding of the nature of science and science self-efficacy in undergraduates involved in research in an introductory geology course

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CHAPTER 1: GENERAL INTRODUCTION

A campus-wide effort is being made at Iowa State University to transform undergraduate science education in order to attract and retain students in science, technology, engineering, and mathematics (STEM) majors. Increasing the number of students enrolled in STEM majors is important economically and socially for this country. The United States needs to increase the number of students graduating with STEM degrees in order to remain competitive in the global workforce (PCAST, 2012). The United States also needs citizens equipped with a basic understanding of science concepts and aware of how science works to make informed decisions regarding public policies. This initiative is seeking to transform undergraduate science education through inquiry and authentic research, so that students experience the excitement of discovery in science.

Introductory science courses frequently communicate science as a collection of facts meant to be memorized, discouraging otherwise high achieving students from pursuing STEM majors (Tobias, 1990). Exposing students to many of the same processes and activities that scientists engage in better communicates that science is something to be explored rather than memorized. Inquiry activities and authentic research experiences are ways to engage and involve students in this process of science. At the university level, inquiry activities will be primarily implemented in large introductory lectures and labs, while authentic research projects will be primarily implemented in sophomore level labs. However, in the introductory geology lab, Geology 100L, we have incorporated both inquiry activities and an authentic research project into the curriculum.
**Thesis organization**

This thesis presents the changes made to the Geology 100L curriculum, starting in the Spring 2011 semester. The second chapter is a paper prepared for submission in the Journal of Geoscience Education, and focuses on the creation and implementation of the research project into the curriculum. It also discusses how nature of science understanding and science self-efficacy of students were affected by this project. The third chapter is a second paper prepared for submission in the Journal of Geoscience Education and focuses on the inquiry based lab activities that have incorporated into the curriculum. This paper gives an overview of the content, structure and focus of each lab activity. Chapter four provides overall conclusions about the effectiveness of the new curriculum.

**REFERENCES:**


CHAPTER 2: AUTHENTIC RESEARCH IN AN INTRODUCTORY GEOLOGY LABORATORY: EFFECTS ON NATURE OF SCIENCE UNDERSTANDING AND SCIENCE SELF-EFFICACY

A paper in preparation for submission to the Journal of Geoscience Education

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ABSTRACT: We changed the curriculum of our introductory geology lab to include a six-week, student driven research project focused on local groundwater and surface water issues, seeking to determine whether or not this experience was an effective means to increase students’ understanding of the nature of science and self-efficacy towards science. In addition to developing the research project curriculum, we worked with other university faculty to create a local hydrology research station which included eight monitoring wells and a stream gage, allowing students to collect their own water-level and water-quality data as well as to retrieve automatically collected data. In order to measure nature of science understanding, we used a modified version of the Student Understanding of Science and Scientific Inquiry questionnaire (Liang et al., 2005; Clough, 2010). We modified a vocational self-efficacy survey (Riggs et al. 1994) to measure science self-efficacy. Both instruments had average Cronbach’s alpha values >0.8, making them reliable for our study. After three semesters of collecting data, we have found that an authentic research project slightly improves, but does not significantly increase overall nature of science understanding or science self-efficacy. Disaggregating the data into demographic sub-groups, nature of science understanding increased relatively more in non-STEM students than STEM students, and science self-efficacy increased relatively more in STEM students than non-STEM students.

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INTRODUCTION

As we move forward in a time when science, technology, engineering and mathematics (STEM) skills are fundamental to our economy, and important decisions need to be made about energy and environmental issues, the United States is faced with a need to transform undergraduate education in order to produce more graduates in STEM fields and increase the scientific literacy of the general public.

The President’s Council of Advisors on Science and Technology (PCAST) suggested in their 2012 “Engaged to Excel” report that in order to maintain economic competitiveness in the future, one million more students must graduate with STEM degrees than the current graduation rate. Three quarters of this goal could be met simply by lowering the attrition rate from STEM fields from 60% to 50% (PCAST, 2012). Undergraduate science education needs to be transformed to address and counter the reasons why these students are leaving STEM fields.

Seymour and Hewitt (1997) found that students often opt out of STEM fields because they do not see the connection between their different science courses. Tobias (1990) found that many otherwise academically strong undergraduates leave STEM fields because they see science as only the passive repetition of facts and are not engaged in their courses. Other researchers have found that students, particularly female students, leave STEM fields because they do not see the social nature or applicability of scientific careers (Matthews, 1994; Eccles, 2005). At the root of these issues lies a misunderstanding of the nature of science (NOS). The NOS describes what science is, how it works, what scientists are like, and, among other things, what role society plays in influencing science (McComas et al., 1998; Clough, 2007). Seeing science as only a collection of facts to be passively repeated is a misunderstanding of the role that discovery, invention, imagination and creativity play in science (Tobias, 1990). Seeing science as an
isolated endeavor is a misunderstanding of how and why scientists collaborate. Effectively teaching the NOS to undergraduate students has the potential to increase the retention of students in STEM field by removing some of the reasons that lead them to leave.

Besides staunching the flow of students out of STEM fields, another option for increasing the number of students graduating with STEM degrees is to increase the number of students initially pursuing STEM degrees. Self-efficacy (SE), the belief in one’s ability to succeed at a given task (Bandura, 1977), is a predictor of both selection and persistence in a given college major (Lent et al., 1984, 1986; Hackett and Betz, 1989; Pajares and Miller, 1995). If a student’s SE influences what degree he/she pursues, increasing a student’s SE can increase their interest in a given career (Lent et al., 1994; Luzzo et al., 1999).

In addition to the need for more STEM majors, the United States also has a need to increase the scientific literacy of the citizenry. The National Science Board (1996) found that more than 60% of the American adults they surveyed did not even have a basic understanding of how science works. Though there are numerous definitions for scientific literacy (e.g., Norris and Phillips, 2003), Holbrook and Rannikmae (2009) put forth a practical definition: a scientifically literate citizen possesses the “skills and values appropriate for a responsible citizen.” Students, as citizens, need to be able to make informed decisions regarding funding for science endeavors, science education, the validity of scientific evidence in the courtroom, and environmental and energy policy decisions (Shamos, 1995; Driver et al., 1996; McComas et al., 1998; Rudolph, 2007; Holbrook and Rannikmae 2009). Misunderstandings about the NOS often prevent citizens from making informed decisions in these areas (Shamos, 1995; Rudolph 2007). Thus, correcting misconceptions about the NOS can increase the ability of citizens to make
informed citizens, increasing their scientific literacy as defined by Holbrook and Rannikmae (2009).

The goal of this paper is the exploration of the effect that the involvement in an authentic research project has on students’ NOS understanding and self-efficacy towards science. We will also use the understanding of NOS to gauge scientific literacy, asserting that understanding the NOS is a fundamental component of scientific literacy (Shamos, 1995; National Research Council, 1996; McComas et al., 2000, Holbrook and Rannikmae, 2007; AAAS, 1989). We also recognize that an understanding of scientific content is also an important component in scientific literacy (National Research Council, 1996; McComas et al., 2000, AAAS, 1989), but was not directly measured in this study.

We share the results obtained from teaching a reformed lab over three consecutive semesters, seeking to answer whether or not incorporating a research project and inquiry-based instruction in undergraduate geology laboratory is effective at increasing students’ understanding of the NOS and science SE.

BACKGROUND

Nature of science (NOS)

As previously stated, the NOS describes what science is, how it works, what scientists are like, etc. (McComas et al., 1998; Clough, 2007). Though no one “nature of science” exists, there are many agreed-upon statements that describe the NOS, like ‘scientific knowledge is tentative’, ‘science requires creativity’, and ‘observations are influenced by prior knowledge and one’s theoretical framework’ (Smith et al., 1997; McComas et al., 1998; Eflin et al., 1999). Statements like these are useful for science education purposes, but are by no means tenets nor should be
taught as such (Clough, 2007, 2011). Statements about the NOS are not tenets because many NOS ideas are very contextual (Clough, 2007); for example, the nature of biology is different than the nature of geology. Like the science content in the class, NOS ideas should be explored and investigated to be truly understood, instead of just learned as fact (Clough, 2007, 2011).

Accurate and effective instruction of the NOS is an important component of science education. Students enter the classroom with many misconceptions about the NOS (Ryan and Aikenhead, 1992; Clough, 1995a; Lederman, 1992; McComas et al. 1998). These misconceptions can prevent students from pursuing STEM degrees and interfere with their growth as informed citizens. Misconceptions have been developed through exposure to misconceptions present in textbooks, media, scientific papers, and science teachers (Robinson, 1969; Cawthron and Rowell, 1978; Ryan & Aikenhead, 1992; Clough, 1995; McComas et al., 1998). There are numerous examples of teaching practices and interventions that have successfully changed students’ views on the NOS (Klopfer and Cooley, 1963; Crumb, 1965; Cossman, 1969; Clough 1995a, 1995b); however, it is also important to note that the NOS will be conveyed to students regardless of whether or not the teacher seeks to do so explicitly (Robinson, 1969; Carey and Strauss, 1970; Dibbs, 1982; McComas et al.,1998). Although inquiry-based science activities often accurately convey the NOS, they are often ineffective in changing students’ views of the NOS (Lederman, 1992; Abd-El-Khalick and Lederman, 2000; Khishfe and Abd-El-Khalick, 2002). Explicit instruction that includes reflection has been found to be the most effective way to change students’ views on the NOS (Abd-El-Khalick et al., 1998; Abd-El-Khalick and Lederman, 2000; Akerson et al., 2000; Khishfe and Abd-El-Khalick, 2002). We seek to incorporate a research project into the course curriculum in order to provide a context for explicit NOS instruction.
**Self-efficacy**

Bandura (1977) first developed the concept of self-efficacy and explained that a person's self-efficacy towards a task is influenced by performance accomplishments, vicarious learning, verbal persuasion, and emotional arousal. Performance accomplishments increase self-efficacy when an individual successfully completes a task (Luzzo et al., 1999), and are arguably the most influential factor in changing self-efficacy (Bandura, 1977). Campbell and Hackett (1986) found that college students who successfully completed math problems (a performance accomplishment) had increased self-efficacy toward math, while students who were unsuccessful at completing the problems had decreased self-efficacy toward math. Similarly Luzzo et al. (1999) found that math self-efficacy and interest in math careers could be increased in students through a performance accomplishment intervention.

Though studies that focus solely on changes in students’ science self-efficacy are less abundant, numerous studies on students’ attitudes toward science have been completed (e.g. Freedman, 1997; French and Russell, 2001; Adams et al., 2007; Barbera et al., 2008). The instruments used in these studies generally also include questions that address self-efficacy toward the specific discipline or science in general (Dagelty et al. 2003; Adams et al., 2007). In introductory chemistry and physics courses, students’ attitudes toward science generally decrease by the end of the semester for traditional, lecture based courses (French and Russell, 2001; Adams et al., 2007; Barbera et al., 2008). Lab activities and more student-centered teaching strategies have been shown to significantly improve students’ attitudes toward science (Freedman, 1997; French and Russell, 2001). In addition to self-efficacy, students’ attitudes toward science have also been shown to serve as a predictor of whether or not a student will
continue pursuing more courses in a discipline (Dagelty and Coll, 2006). Though these studies have not specifically focused on science self-efficacy, we see that introductory science courses generally decrease students’ confidence and attitude toward science, pushing them away from continuing to pursue science majors. We seek to increase students’ self-efficacy toward science by giving them an opportunity to successfully complete a research project.

**COURSE OVERVIEW**

Geology 100L is an introductory lab course associated with the introductory physical geology lecture course offered at a large U.S. Midwestern research university. Students enrolled in the lecture are not required to enroll in the lab course; however, the lecture is a prerequisite or co-requisite for the lab. Both the lecture and the lab course fulfill the University’s general education science requirements. The lab, offered both fall and spring semesters, consists of 3-4 sections with up to 25 students meeting once a week for two hours. Approximately 2/3 of the students are non-geology and non-STEM majors. The class is usually taught by graduate student teaching assistants (TAs); one of the TAs in the Spring 2011 semester was an undergraduate student. TA assignments change every semester and only occasionally a TA will teach the lab for more than one semester.

We have transformed the curriculum of our introductory lab course (Geology 100L) so that students have an authentic science experience through a research project, and are exposed to explicit instruction on the NOS during the research project and other parts of the course. We have added a six-week research module focusing on groundwater and surface water processes of the local area. Weaver et al. (2006) describe authentic research as research where students contribute to a real research project, design their own project or procedure, and do not know the
results beforehand. Many examples of this type of research modules have been developed by the Center for Authentic Science Practice in Education (CASPiE, Weaver et al., 2006).

For our research project, the students develop open-ended research questions and hypotheses about the local water system, ranging in focus from interactions between the surface and groundwater systems and investigating factors that influence on water quality. Students determine what data they need to collect to answer their questions (i.e. nitrate concentrations, water levels, water pH), collect their data, and summarize their results in a conference style poster. Students present their posters both in class and at an evening poster session, where they interact with faculty and staff and discuss their research on the local water system. Even though we used the CASPiE model as a basis for designing our research project, a major difference from the CASPiE model is that our students are not directly engaged in faculty-led research projects like the students involved in CASPiE modules; instead, their research contributes to a growing database of local water-quality data created for this project.

The research module is interwoven into the lab curriculum, occupying six of the fifteen weekly lab periods (Table 1). The first week of the module is a field exercise where TAs introduce students to the field site and equipment, basic groundwater concepts, and the research component of the lab. Students learn how to take water level measurements, bail water from the wells to make water quality measurements, how to measure water pH, and how to measure nitrate and phosphorus concentrations using a hand-held colorimeter. As homework from the field assignment, students come up with two research questions about local water issues. The following week the class discusses these questions, also discussing the characteristics of a good, scientific research question. For the remainder of the class period and the following week of class, groups of students select one question to explore using two physical models, the stream
table and a groundwater “antfarm” model. In this exploration phase, students choose a research question based on the models, form a hypothesis, plan how they will collect data, decide what data will be meaningful, collect data using the physical models, and briefly present their results to the class. This practice project is an essential step as it gives students the opportunity to form and test research hypotheses, something they usually have no previous experience with.

After this practice, student groups form their large project research question, their hypothesis, and plan what data they will need to answer their questions (i.e. phosphorus concentrations, land use, etc.). Examples of student research questions can be found in Figure 1. Groups draft and share their field-based research proposal with their TA; TAs provide feedback and students use this feedback to refine and edit their proposal. Student proposals are usually approved by the TAs after three iterations; once a proposal is approved, the students can begin to collect data. Students are given one lab period to collect data, but students collect most of their data outside of class time, checking out the equipment that they will need. A list of equipment available to the students is shown in Table 2. Student groups generally collect three sets of measurements for their project and use the database of past data as a supplement. After students have had two weeks to collect data, they submit a draft of their methods section to their TA for feedback and evaluation, usually during week 10 of the semester.

Two weeks before the final draft of the poster is due, students are given a work day in lab. During this time, students peer-review their classmates’ abstracts and use the rubric that will be used on their poster to evaluate posters from previous semesters. We have found that it is important to give the students practice and training in the different components of the research project in order to prepare them for success on the final poster. Many students have no experience with scientific research, so teaching them how to write a research question,
hypothesis, methods section, abstract, and poster are all necessary steps for the success of this project.

The final component of the research project is the preparation of a research poster. Students give an oral presentation of their poster in class, and then present again at a poster session where expert judges (faculty members engaged in water-related research) evaluate the students’ posters. Other university faculty and administrators attend the event and interact with the students as well. This poster session allows the students to gain a broader perspective on their research work and to share their excitement about their research findings.

One reason for focusing the research project on surface water and groundwater topics is that an understanding of surface water and groundwater is important for students to possess as they make decisions about how to address surface water quality issues, the environmental impacts of hydrofracking, and water sources/water shortage issues, etc.. Though this understanding is important, many students enter and leave college with numerous misconceptions about groundwater (Dickerson et al., 2005; Dickerson and Dawkins, 2004). Many of these misconceptions exist and persist because of the unseen and abstract nature of groundwater (Dickerson et al., 2007; Schwartz et al., 2011). Deep understanding of groundwater concepts require students to use spatial reasoning, which is underdeveloped in most students (Dickerson et al., 2007). Hands-on activities that focus on improving students spatial reasoning (e.g. puzzles, drawing, mapping, constructing physical models) can help improve students’ understanding of groundwater concepts (Baker and Piburn, 1997; Dickerson et al., 2007). Three dimensional physical models can also increase students’ understanding of groundwater concepts (Dickerson et al., 2007). We seek to engage students in spatial reasoning
by having them explore groundwater concepts with our three-dimensional, “antfarm” groundwater model during the mini research experience.

The curricular changes outlined above have been implemented in stages in this course. Equipment had not yet been purchased or installed in the Spring 2011 semester, so students completed a pilot version of the research project, in which they created a proposal for a project that would study flooding. Students made a poster on their proposal and participated in an evening poster session. During the Spring 2011 semester, a few questions addressing NOS issues were included in weekly quizzes and students also completed a short written reflection about how the research experience had influenced their perceptions about the NOS.

Starting in the Fall 2011 semester students had access to the equipment listed in Table 2 to collect their water quality measurements, so the research project was implemented as described above. Figure 2 shows an image of the newly created hydrologic field station. As we continued to refine the curriculum, we removed the weekly quizzes from the course which eliminated consistent NOS reflection from the curriculum as well. We also found that students did not take the written reflection about the research experience’s influence on their understanding of the NOS seriously, so we removed that component as well. Consequently, students were not asked to explicitly reflect on NOS ideas in the Fall 2011 semester. We made efforts to encourage and guide TAs in leading discussions about the NOS during the lab activities, but found that TAs were inconsistent in implementing this into the course.

Spring 2012 was the second complete implementation of the new curriculum, with minor tweaks to the research project. Again, student quizzes and assignments did not include NOS reflection questions, but efforts to encourage TAs to address NOS ideas in the lab activities continued.
Seven different TAs have taught the course over the three semesters; there is no indication that an individual TA had a significant impact on the data we collected on students’ NOS and self-efficacy.

METHODS

To measure understanding of the NOS, we used a modified version of the Student Understanding of Science and Scientific Inquiry (SUSSI) (Liang et al., 2006). This modified version of the SUSSI is a 40 question survey that contains eight different categories (Appendix A). Each category addresses a different aspect of the NOS and contains four statements to be evaluated using a 5-point Likert scale, followed by a short answer response prompt asking students to elaborate on their views in that category (Figure 3). Five of the categories are from the original instrument, with two of those being modified by Clough et al. (2010). The other three categories were created by Clough et al. (2010). This is the first study in which these eight categories have been used together as a complete instrument. We used Cronbach’s alpha to evaluate the internal reliability for this modified version of the SUSSI. Cronbach’s alpha values for the whole instrument ranged from 0.65 to 0.85 over the three semesters (Table 3). Post-test alpha values were higher than pre-test alpha values for all semesters, with post-test alpha values ranging from 0.70 to 0.84, while pre-test alpha values ranged from 0.65 to 0.83 (Table 3). These values fall within an acceptable range, suggesting that the modified version of the SUSSI is not only reliable, but consistently reliable among the different populations each semester.

The Likert-scale responses from the SUSSI were scored on scale of 1 to 5. If the ‘expert’ response to a question was Strongly Agree (SA), students responding SA would receive a score of 5 and students responding Strongly Disagree (SD) would receive a score of 1. Similarly, if
the expert response was SD, students responding SD would receive a score of 5 and students responding SA would receive a score of 1. Table 4 shows an example of how Likert responses were coded. In this scoring system, positive changes from pre- to post-tests represent students moving toward a more expert view.

The short answer question in each category of the SUSSI allows us to verify that the quantitative results (Likert responses) accurately reflect the student’s views. In order to verify the agreement, three evaluators developed a grading rubric for the short answer responses by individually grading five students’ responses and then discussing any disagreements. With the refinement of the rubric, the evaluators graded 85% of the responses the same way (either stating the Likert scores did or did not match student views expressed in the short answer responses). After inter-rater reliability was established, the remaining student responses were divided up, including a five student overlap to verify that the inter-rater reliability levels remained acceptable. Again, 85% of responses (34/40) were graded the same by all raters in each submission.

For our purposes, we focused our analysis of short answer responses to “consistent” or “not consistent” with Likert responses, a method used by Liang et al. (2005) in the original paper where the SUSSI was first described. Due to the complex nature of analyzing qualitative data and NOS understanding, it was not possible to take a category level approach to look at a student’s written response and state if her/his written work was consistent with his/her Likert responses. In many instances, different NOS ideas were present in a category, and students did not necessarily hold the same view on each NOS idea. Therefore, a more nuanced approach was developed to look for consistency in students’ thinking between individual Likert selections and written explanations. Figure 4 shows an example of how the short answer responses were
graded. A detailed explanation of the rubric the evaluators created and used for grading agreement is described in Appendix D. Evaluation of the short answer responses found that 90% of student short answer responses were consistent with their Likert responses, further supporting the reliability of the instrument. Others have done more extensive evaluation, grading short answer responses as ‘naive’, ‘traditional’, or ‘informed’ (Liang et al., 2006; Desaulniers Miller et al., 2010), but we found that determining whether or not short answer responses were consistent with Likert responses was sufficient for our research.

To assess students’ self-efficacy, we used a SE survey modified from a vocational SE survey described in Riggs et al. (1994). We took the ten items from their personal efficacy scale and replaced the words “my job” with the word “science.” For example, “my future in my job is limited because of my lack of skills” became on our instrument: “My future in science is limited because of my lack of skills.” Student interviews were not performed to verify that the students interpreted the word changes as predicted, but Cronbach’s alpha for the modified instrument was >0.8 each semester for pre- and post-tests, which is consistent for other SE scales (Luzzo et al., 1999), so we deemed the instrument reliable. A copy of our instrument can be found in Appendix C.

The responses from the SE survey were scored with 10 representing the favorable response and 1 the unfavorable response. For questions 1, 5, 7, and 9 the favorable response was 10 (completely able or completely true), so student responses were the score the students received. For questions 2, 3, 4, 6, 8, and 10, the favorable response was 1 (not able or not true at all) so students’ scores were reversed so that a student responding 1 received a score of 10 and a student responding 10 received a score of 1. Similar to the SUSSI, a positive change in score represents students moving toward a more favorable view.
The Institutional Review Board reviewed and approved these instruments and the research was determined to be ‘exempt’ following federal regulations. Each instrument was made available to the students enrolled in Geology 100L through the class’s online course management system during the first two weeks of the semester (referred to as pre-test) and again during the last two weeks of the semester (referred to as post-test). Students usually took 20-40 minutes to complete the SUSSI, and 10-15 minutes to complete the self-efficacy survey. Allowing students two weeks to take the survey ensured a high response rate. Students received course credit (5 points; approximately 1% of their grade) for completing each survey. The surveys were given in the Spring 2011, Fall 2011, and Spring 2012 semesters. Student responses were only included in the analysis if the student completed both the pre- and post-test. Approximately 75% of students enrolled in the labs completed both the pre- and post-tests for each instrument each semester.

In order to analyze the data we gathered, we used two different statistical methods. First, was a comparison of pre- and post-test scores using a One-way analysis of variance (ANOVA). This type of analysis determines whether or not differences seen in mean scores (pre-test and post-test) are explained by random variation in the population, or by the treatment being tested. In our case, this allows us to see if total NOS understanding or total science self-efficacy has been significantly affected by the new curriculum. Though this is a quick and relatively simple gauge of the difference between pre- and post-test scores, it is often not subtle enough to determine small improvements, or gauge effectiveness of the intervention among students with a variety of levels of understanding. For this reason, we also compared the normalized changes that occurred each semester. Normalized changes are a measure of how much a student improved, given the room they had to improve. Small improvements in students with higher pre-
test scores are given the same weight as larger improvements in students with lower pre-test scores. We used the equation developed by Marx and Cummings (2007) as shown in Figure 5 to calculate or normalized changes. Subtle changes in pre-test and post-test scores are more clearly seen when looking at normalized changes along with the results from the ANOVA. We found normalized changes to be especially useful for this study as many different NOS ideas are present within the SUSSI and small changes in overall score, which can represent improvement in one or two ideas about the NOS, is significant, though it may not appear so when doing an ANOVA.

RESULTS

NOS understanding

We will look at the data for each semester individually because of the different stages of implementation of the research project and different degrees of assigned explicit reflection on the NOS between the three semesters.

For the Spring 2011 semester, the results from the One-way ANOVA show an increase in students’ understanding of NOS concepts following the pilot research project, but not at a significant level (Figure 6). Normalized changes for the SUSSI this semester were 11.5% (Figure 7). Positive normalized changes occurred in every demographic group (Table 5). Students with less science experience (those with no or one previous college science course and non-STEM majors) had the largest normalized gains, although the differences were only significant between non-STEM majors and STEM majors (Figure 8). Freshmen and sophomores had non-significantly higher normalized changes that juniors and seniors. Female students had non-significantly higher normalized changes than male students. As we look at what NOS
ideas gains were focused in, we see significant increases in students understanding about the role of imagination and creativity in science, specifically that scientists use their imagination and creativity when the collect, analyze, and interpret data, and that imagination and creativity do not conflict with a need to be unbiased (Figure 9).

Looking at the next semester, Fall 2011, the results of the ANOVA do not show a noticeable increase in students’ understanding of NOS concepts as a result of the research project (Figure 6). But, gains were still made as normalized changes were positive, with an 8.6% increase (Figure 7). Students with two or three previous college-level science courses had the highest normalized changes, and students with one or four courses had negative normalized changes (Table 5). Non-STEM students had higher normalized changes, but not at a significant level (Figure 8). Juniors had non-significantly higher normalized changes than other students. Females again had non-significantly higher normalized changes than male students. Significant increases were seen in students’ understanding that a universal, lock-step scientific method does not exist and that scientific theories are created by human minds and not existing in nature to be found (Figure 10).

Lastly, in the Spring 2012 semester, the results of the ANOVA again do not show a significant increase in students’ understanding of NOS concepts (Figure 6), while analysis of normalized changes shows a 7.2% increase (Figure 7). Students with four previous college-level science courses had the highest normalized changes compared to students with other levels of science course experience (Table 5). Non-STEM students had significantly higher normalized changes than STEM students, and STEM students had negative normalized changes (Figure 8). Sophomores had non-significantly higher normalized changes than other students. Females had higher normalized changes than males, but not at a significant level. Significant increases in
students understanding the imagination and creativity do not interfere with logical reasoning occurred this semester (Figure 11).

**Science self-efficacy**

We will look at changes in science self-efficacy for each individual semester because of the different stages of implementation of the research project over the three semesters.

Like the overall results for the SUSSI results from the ANOVA tests do not show a significant increase in students’ science self-efficacy in the Spring 2011 semester as a result of the pilot research project (Figure 12). However, overall normalized changes were 11.8%, so gains in science self-efficacy were made this semester (Figure 13). Female students had non-significantly higher normalized changes than males (Table 6). Juniors and seniors had higher normalized gains compared with freshmen and sophomores (Table 6). Students with more than four college-level science courses had higher normalized changes than students with other levels of science course experience (Table 6). STEM students had higher normalized changes than non-STEM students, although the difference was not statistically significant (Table 6).

Fall 2011 was the first semester students completed the full research project, including collecting data, and the ANOVA test shows losses in science self-efficacy (Figure 12). A slight loss in normalized changes also occurred, with 0.9% losses (Figure 13). Females had negative normalized changes, while male students had positive normalized changes (Table 6). All class ranks except juniors had negative normalized changes (Table 6). Students with no or one previous college-level science course had negative normalized changes (Table 6). Non-STEM students had negative normalized changes, while STEM students had positive changes (Table 6).
Science self-efficacy changes in Spring 2012 were similar to the changes observed in Spring 2011. Although the results of the ANOVA show that post-test means were slightly lower than pre-test means (Figure 9), normalized changes were positive, with a 5.9% increase (Figure 10). Female students again had non-significantly higher normalized changes than males (Table 6). This semester freshmen had higher normalized changes than sophomores and juniors (Table 6); no seniors were enrolled in the lab that semester. Students with more than four previous college-level science courses had the highest normalized changes compared to students with other levels of science course experience (Table 6). Once again, STEM students had higher normalized changes than non-STEM students (Table 6).

**DISCUSSION**

Our results suggest that localized increases are occurring in students’ understanding of the NOS and their self-efficacy toward science. ANOVA results do not show a statistically significant increase in students’ scores from pre-test to post-test for either NOS understanding or self-efficacy, but each semester saw positive normalized changes in understanding of the NOS, and positive normalized changes in science self-efficacy for the Spring 2011 and Spring 2012 semesters.

It is not surprising that the results from the SUSSI do not show large changes in NOS understanding after students complete a research project. The most effective ways found to change NOS views have been through consistent and explicit discussion about the NOS (Abd-El-Khalick et al., 1998; Abd-El-Khalick and Lederman, 2000; Akerson et al., 2000; Khishfe and Abd-El-Khalick, 2002). Research on the NOS has shown that implicit examples of the NOS are not effective in changing students’ views on the NOS (Lederman, 1992; Abd-El-Khalick and
Lederman, 2000; Khishfe and Abd-El-Khalick, 2002; Schwartz et al., 2004). Indeed, the highest gains in NOS understanding appeared in the Spring 2011 semester when students were asked to reflect on different NOS ideas on weekly quizzes and in a final written assignment. Our results show that a research project by itself is an implicit example of the NOS and as such was insufficient to impact our students’ views on the NOS.

To truly attempt to change students’ NOS views, we need to incorporate explicit examples and discussions about the NOS. However, this becomes increasingly challenging as most labs are taught by TAs, who themselves have different levels of understanding of the NOS and different levels of comfort in teaching about the NOS. Research has shown that teacher understanding of the NOS plays a huge role on student understanding of the NOS (Robinson, 1969; Carey and Strauss, 1970; Dibbs, 1982; McComas et al., 1998). We encouraged the TAs to bring up NOS in discussion during the lab activities, but found that TAs were inconsistent in adopting these discussions into their teaching practices.

In order to ensure that NOS ideas will be explicitly addressed in the future, we added assigned weekly NOS reflection questions to the course the Fall 2012 semester. We have also continued to train the TAs in the pedagogical importance of NOS teaching during our weekly meetings. No curriculum measures can fully counteract an inaccurate presentation of the NOS from the TA (Duschl, 1987); however, we believe these assigned reflection questions, though not as effective without follow-up discussion, will be a step towards more adequately utilizing the transformed curriculum and research project in increasing students’ understanding of the NOS. SUSSI data is being gathered for the Fall 2012 semester but will not be presented in this paper.

Though the ANOVA results do not report significant improvements in students’ self-efficacy toward science, that we observed small improvements is significant, considering that
most students’ attitudes and self-efficacy toward science decrease as a result of their introductory science courses (French and Russell, 2001; Adams et al., 2007; Barbera et al., 2008). In addition, it is also worthwhile to note that groundwater concepts are difficult for students to grasp, both because of the inability to see the system, and the spatial reasoning that is required to visualize the system (Dickerson et al., 2007; Schwartz et al., 2011). Though we attempt to engage students in spatial visualization about groundwater through the mini-research project, there is room to increase the degree in which we engage students’ spatial reasoning during the project. Consequently, it is possible that the gains in self-efficacy for students are being damped as students recognize that though they have completed the step of the research project successfully, they still do not fully grasp the groundwater concepts.

The exact reason for slight decrease in students’ science self-efficacy that was observed in the Fall 2011 semester is unknown to the researchers. These losses are focused in groups with less science experience (no or one previous science course, non-STEM students, and freshman and sophomore students). Losses in these demographic groups do not appear in other semesters, suggesting that this was unique for the Fall 2011 semester. It is possible that the “rough spots” present in the first full implementation of the research project caused students to feel unsuccessful. These confounding factors might have been removed the Spring 2012 semester with the second full implementation of the project. Self-efficacy data is being collected in the Fall 2012 semester and can provide more insight into whether or not these lower scores are unique to the Fall 2011 semester. Also, further investigation through interviews could possibly provide more insight into students’ science self-efficacy beliefs.

We find interesting the trend that shows that non-STEM students made greater gains in NOS understanding, while STEM students made greater gains in science self-efficacy. It
appears that the research project helps non-STEM students better understand what science is like (Table 5), but is not as useful in increasing their science self-efficacy (Table 6). A speculation for the lower self-efficacy improvements in non-STEM students is that they do not see themselves successfully completing the research project, even though this is not reflected in their grades or performance; unsuccessful attempts at performance accomplishments have been shown to decrease self-efficacy (Campbell and Hackett, 1986). The research project, however, seems useful for increasing STEM students’ science self-efficacy, a positive result that can lead to better retention of students in STEM fields.

CONCLUSIONS

Localized improvements were seen each semester in students understanding of the NOS and their self-efficacy toward science. The improvements were not wide-spread or large enough to appear in an ANOVA test, but were revealed through positive normalize changes. These results suggest that participating in an authentic research project is only nominally effective at changing students understanding of the NOS and science self-efficacy. The authentic research project provides a context for students to experience how science works and what it is like, but is not sufficient to change students’ views on the NOS. The most significant increases observed in NOS understanding occurred in the Spring 2011 semester when students reflected on NOS ideas through quiz questions. This supports the understanding that active reflection on NOS ideas is a key component necessary for changing students understanding of the NOS. The research project also appears to increase STEM students’ science self-efficacy more than it increases non-STEM students’ science self-efficacy, suggesting that it has potential to help retain STEM students in STEM disciplines.
Acknowledgements:

This project was funded by the Howard Hughes Medical Institute. Funding for the field equipment and well installation was provided by the Howard Hughes Medical Institute, the Iowa Math and Science Education Program, Iowa State University’s Department of Geological and Atmospheric Sciences and College of Liberal Arts and Sciences. We would also like to thank Bill Simpkins, Chris Rehmann, Kristie Franz, Mark Mathison, and Jake Smokovitz for their help in installation and implementation of the project, and Jesse Wilcox, for his help in the evaluation of the SUSSI data.

REFERENCES


Clough, M.P. 1995b. How to accurately portray the nature of science while teaching science content. *In* Finley, F., Allchin, D., Rhees, D., and Fitfield, S., eds., The Proceedings of the third international history, philosophy and science teaching conference, Minneapolis, MN.


### Table 1: An example of the weekly lab schedule before and after changes to the curriculum.

Classes devoted to the research project are in bold font and inquiry based labs are shown in red.

<table>
<thead>
<tr>
<th>Week</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction to measurements and earth</td>
<td>Introduction + NOS tubes activity</td>
</tr>
<tr>
<td></td>
<td>processes</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Plate Tectonics</td>
<td><strong>Introductory Field Activity</strong></td>
</tr>
<tr>
<td>3</td>
<td>Earthquakes</td>
<td>Streams and Groundwater (practice investigation)</td>
</tr>
<tr>
<td>4</td>
<td>Mineral Identification</td>
<td>Streams and Groundwater (practice investigation)</td>
</tr>
<tr>
<td>5</td>
<td>Mineral Identification</td>
<td>Mineral Identification</td>
</tr>
<tr>
<td>6</td>
<td>The Rock Cycle + Igneous Rocks</td>
<td>Rock Identification</td>
</tr>
<tr>
<td>7</td>
<td>Sedimentary Rocks</td>
<td>Rock Identification</td>
</tr>
<tr>
<td>8</td>
<td>Metamorphic Rocks</td>
<td>Rock Cycle</td>
</tr>
<tr>
<td>9</td>
<td>Geologic Time</td>
<td>Field Day</td>
</tr>
<tr>
<td>10</td>
<td>Stream Processes</td>
<td>Plate Tectonics</td>
</tr>
<tr>
<td>11</td>
<td>Groundwater Processes</td>
<td>Pangea</td>
</tr>
<tr>
<td>12</td>
<td>Geologic Structures and Maps</td>
<td>Work Day</td>
</tr>
<tr>
<td>13</td>
<td>Topographic Maps</td>
<td>Topographic Maps</td>
</tr>
<tr>
<td>14</td>
<td><strong>Thanksgiving Break</strong></td>
<td>Thanksgiving Break</td>
</tr>
<tr>
<td>15</td>
<td>Glacial Processes and Climate Change</td>
<td>Poster Presentations + Virtual Volcano Activity</td>
</tr>
<tr>
<td>16</td>
<td>Quiz</td>
<td>Geologic Time + Capstone Activity</td>
</tr>
</tbody>
</table>
Table 2: A general list of equipment available for student checkout.

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water-level tape</td>
<td>2</td>
</tr>
<tr>
<td>Handheld pH meter</td>
<td>2</td>
</tr>
<tr>
<td>Pocket colorimeter</td>
<td>2</td>
</tr>
<tr>
<td>Nitrate reagents</td>
<td>As needed</td>
</tr>
<tr>
<td>Phosphate reagents</td>
<td>As needed</td>
</tr>
<tr>
<td>Bailer (pvc pipe)</td>
<td>4</td>
</tr>
<tr>
<td>Well key</td>
<td>3</td>
</tr>
<tr>
<td>Wells--not outfitted</td>
<td>4</td>
</tr>
<tr>
<td>Wells--outfitted with continuous pH, temperature and conductivity probes</td>
<td>4</td>
</tr>
<tr>
<td>Stream gauge</td>
<td>2 (1 USGS, 1 ours)</td>
</tr>
</tbody>
</table>
Table 3: Cronbach’s Alpha values for the SUSSI by semester.

<table>
<thead>
<tr>
<th></th>
<th>S11</th>
<th>F11</th>
<th>S12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre</td>
<td>0.6502</td>
<td>0.7229</td>
<td>0.8338</td>
</tr>
<tr>
<td>Post</td>
<td>0.7021</td>
<td>0.8211</td>
<td>0.8535</td>
</tr>
</tbody>
</table>
Table 4: SUSSI Likert response coding example. Appendix A contains the SUSSI statements.

<table>
<thead>
<tr>
<th>Question</th>
<th>Scientific Observations A</th>
<th>Scientific Observations B</th>
<th>Scientific Observations C</th>
<th>Scientific Observations D</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Expert Response”</td>
<td>SA</td>
<td>SD</td>
<td>SD</td>
<td>SA</td>
</tr>
<tr>
<td>Student Response</td>
<td>SD</td>
<td>D</td>
<td>SD</td>
<td>SA</td>
</tr>
<tr>
<td>Coded Score</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>
Table 5: Table of normalized changes by demographics for the SUSSI instrument. The differences between Non-STEM and STEM students in Spring 2011 and Spring 2012 are significant: p=0.37 and p=0.029, respectively.

<table>
<thead>
<tr>
<th>Demographics</th>
<th>Spring 2011</th>
<th>Fall 2011</th>
<th>Spring 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>12.7%, n=34</td>
<td>9.6%, n=23</td>
<td>11.8%, n=21</td>
</tr>
<tr>
<td>Male</td>
<td>8.5%, n=13</td>
<td>7.7%, n=23</td>
<td>4.1%, n=27</td>
</tr>
<tr>
<td></td>
<td>Rank</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rank</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freshman</td>
<td>21.2%, n=10</td>
<td>7.9%, n=11</td>
<td>4.7%, n=8</td>
</tr>
<tr>
<td>Sophomore</td>
<td>14.6%, n=12</td>
<td>8.9%, n=16</td>
<td>14.5%, n=10</td>
</tr>
<tr>
<td>Junior</td>
<td>8.7%, n=11</td>
<td>16.7%, n=8</td>
<td>4.2%, n=22</td>
</tr>
<tr>
<td>Senior</td>
<td>4.3%, n=14</td>
<td>3.1%, n=11</td>
<td>10.5%, n=8</td>
</tr>
<tr>
<td></td>
<td>No. of college level science courses taken</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of college level</td>
<td>0</td>
<td>20.9%, n=5</td>
<td>11.5%, n=16</td>
</tr>
<tr>
<td></td>
<td>science courses taken</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>25.9%, n=6</td>
<td>-1.2%, n=9</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>12.7%, n=10</td>
<td>21.5%, n=8</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>13.8%, n=5</td>
<td>25.5%, n=1</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>8.3%, n=3</td>
<td>-1.2%, n=3</td>
</tr>
<tr>
<td></td>
<td>&gt;4</td>
<td>1.5%, n=12</td>
<td>3.3%, n=9</td>
</tr>
<tr>
<td></td>
<td>Major</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-STEM</td>
<td>15.1%, n=34</td>
<td>10.5%, n=33</td>
<td>13.1%, n=30</td>
</tr>
<tr>
<td>STEM</td>
<td>2.3%, n=13</td>
<td>3.8%, n=13</td>
<td>-1.9%, n=18</td>
</tr>
</tbody>
</table>
Table 6: Table of normalized changes by demographics for the self-efficacy instrument.

<table>
<thead>
<tr>
<th></th>
<th>Spring 2011</th>
<th>Fall 2011</th>
<th>Spring 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>15.5%, n=34</td>
<td>-5.5%, n=21</td>
<td>10.2%, n=21</td>
</tr>
<tr>
<td>Male</td>
<td>2.0%, n=13</td>
<td>5.2%, n=20</td>
<td>3.8%, n=27</td>
</tr>
<tr>
<td><strong>Rank</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freshman</td>
<td>2.5%, n=10</td>
<td>-4.6%, n=13</td>
<td>11.1%, n=9</td>
</tr>
<tr>
<td>Sophomore</td>
<td>9.8%, n=12</td>
<td>-3.7%, n=16</td>
<td>7.7%, n=17</td>
</tr>
<tr>
<td>Junior</td>
<td>17.9%, n=11</td>
<td>15.3%, n=8</td>
<td>2.3%, n=21</td>
</tr>
<tr>
<td>Senior</td>
<td>15.2%, n=14</td>
<td>-4.8%, n=9</td>
<td>n/a</td>
</tr>
<tr>
<td><strong>No. of college level science courses taken</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>9.5%, n=5</td>
<td>-9.8%, n=17</td>
<td>4.7%, n=5</td>
</tr>
<tr>
<td>1</td>
<td>15.7%, n=6</td>
<td>-2.0%, n=8</td>
<td>0.7%, n=6</td>
</tr>
<tr>
<td>2</td>
<td>2.5%, n=10</td>
<td>12.8%, n=8</td>
<td>2.1%, n=15</td>
</tr>
<tr>
<td>3</td>
<td>4.0%, n=5</td>
<td>1.8%, n=2</td>
<td>0.8%, n=12</td>
</tr>
<tr>
<td>4</td>
<td>-3.4%, n=5</td>
<td>10.5%, n=3</td>
<td>12.6%, n=2</td>
</tr>
<tr>
<td>&gt;4</td>
<td>26.1%, n=12</td>
<td>0.6%, n=8</td>
<td>23.6%, n=8</td>
</tr>
<tr>
<td><strong>Major</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-STEM</td>
<td>11.1%, n=34</td>
<td>-1.9%, n=32</td>
<td>2.8%, n=28</td>
</tr>
<tr>
<td>STEM</td>
<td>13.4%, n=13</td>
<td>1.5%, n=14</td>
<td>10.6%, n=19</td>
</tr>
</tbody>
</table>
Figure 1: Examples of student created research questions from various semesters.

- Does an Iowa State football game at Jack Trice Stadium, in addition to commuter traffic, parking, and tailgating, have a short term effect on specific pollutant levels of nearby Squaw Creek?
- How will precipitation affect phosphorus levels in the stream and the wells?
- How does temperature affect nitrate and phosphorus levels?
- How do discharge and depth to water in wells correspond?
- How do chemical levels vary midstream and at the confluence of Squaw Creek and Skunk River?
Figure 2: A map of the newly created hydrology field site. The field site contains eight monitoring wells and a stream gage. It is within walking distance of campus. This image was created using Google Earth.
Figure 3: An example of a category in the SUSSI. This is the Imagination and Creativity category.

<table>
<thead>
<tr>
<th></th>
<th>Scientists use their imagination and creativity when they collect data.</th>
<th>SD</th>
<th>D</th>
<th>U</th>
<th>A</th>
<th>SA</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Scientists use their imagination and creativity when they analyze and interpret data.</td>
<td>SD</td>
<td>D</td>
<td>U</td>
<td>A</td>
<td>SA</td>
</tr>
<tr>
<td>B</td>
<td>Scientists do not use their imagination and creativity because these conflict with their logical reasoning.</td>
<td>SD</td>
<td>D</td>
<td>U</td>
<td>A</td>
<td>SA</td>
</tr>
<tr>
<td>C</td>
<td>Scientists do not use their imagination and creativity because these can interfere with the need to be unbiased.</td>
<td>SD</td>
<td>D</td>
<td>U</td>
<td>A</td>
<td>SA</td>
</tr>
</tbody>
</table>

Explain why scientists use OR do not use imagination and creativity, and provide examples to support your answer.
**Figure 4**: An example of short answer response analysis. These are student responses to the Development and Acceptance of Scientific Ideas category. The first student response set was graded as consistent. Although the Likert scores for statements A and C seem to be contradictory, the student explains that ideas can be both developed quickly and over a long period of time. He/she justifies the contradiction with their written response, so it is graded as consistent. The second student response set was graded as “Not consistent” because his/her Likert response to statement C does not agree with their written response.

<table>
<thead>
<tr>
<th></th>
<th>A. Credible scientific ideas are <strong>usually</strong> generated in a matter of days, weeks or months.</th>
<th>B. Scientific ideas <strong>usually</strong> come to be accepted by the scientific community in a matter of days, weeks or months.</th>
<th>C. Credible scientific ideas are <strong>usually</strong> generated over a period of years to decades.</th>
<th>D. Scientific ideas <strong>usually</strong> come to be accepted by the scientific community over a period of years to decades.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4 5 4 y</td>
<td>An idea may be developed very quickly, but it would probably take months to years to be tested and widely accepted. The idea that the earth was round would have been developed in the span of a few seconds. The length of time it took to test the hypothesis and have it widely accepted took much longer.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4 2 4 n</td>
<td>Scientific ideas take a great deal of time to be generated and accepted -- usually decades. This is because it takes a lot of time to the proper testing and to get the back of the community. One example of this is the theories behind gravity.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 5: The following equation describes how we calculated normalized changes and is taken from Marx and Cummings (2007).

=IF(Pre<Post, (Post-Pre)/(Total Score-Pre), (Post-Pre)/Pre)
Figure 6: One-way ANOVA analysis of total SUSSI scores comparing pre- and post-test scores. Total scores are out of 140. The gray line represents the grand mean for the data set; the green line through each diamond represents the mean for each subset of data. The green lines at the tips of the diamonds represent the 95% confidence intervals. The black lines above and below the diamonds represent the maximum and minimum scores observed on the instrument.

Spring 2011: (n=47) Pre-test mean: 114.2; Post-test mean: 118.4
Fall 2011: (n=46) Pre-test mean: 116.6; Post-test mean: 117.7
Spring 2012: (n=50) Pre-test mean: 117.2; Post-test mean: 117.6
Figure 7: One-way ANOVA analysis of normalized changes in SUSSI scores by semester. Spring 2011=11.5%; Fall 2011=8.6% Spring 2012=7.3%
Figure 8: One-way ANOVA analysis of normalized changes of Non-STEM majors versus STEM majors. **Spring 2011**: n=47, p=0.037  **Fall 2011**: n=46  **Spring 2012**: n=50, p=0.029
Figure 9: One-way ANOVA analysis individual statements of the SUSSI. Significant increases were seen in the following concepts for the Spring 2011 semester: **Imagination and Creativity A**: “Scientists use their imagination and creativity when they collect data. (SA)” p=0.022. **Imagination and Creativity B**: “Scientists use their imagination and creativity when they analyze and interpret data. (SA)” p=0.027. **Imagination and Creativity D**: “Scientists do not use their imagination and creativity because these can interfere with the need to be unbiased. (SD)” p=0.0004.
Figure 10: One-way ANOVA analysis for individual SUSSI statements from Fall 2011. Significant gains were seen in the following concepts: **Methodology of Scientific Investigations A**: “Considering what scientists actually do, there really is no such thing as the scientific method. (SA)” $p=0.008$. **Methodology of Scientific Investigations B**: “Scientists follow the same step-by-step scientific method. (SD)” $p=0.012$. **Discovery and Invention statement A**: “Scientific theories (for example, atomic theory, plate-tectonic theory, gene theory) are discovered. (SD)” $p=0.033$. 

![Graphs showing pre and post scores for Methodology A, Methodology B, and Discovery and Invention A](image-url)
Figure 11: One-way ANOVA analysis for individual SUSSI statements from Spring 2012. Significant gains were seen in the following concept: **Imagination and Creativity C:** “Scientists do **not** use their imagination and creativity because these conflict with their logical reasoning. (SD)” p=0.034.
Figure 12: One-way ANOVA analysis of total self-efficacy scores comparing pre- and post-test scores. Total scores are out of 100. **A**: Overall results Spring 2011 (n=47). Pre-test mean: 63.0; Post-test mean: 66.1  **B**: Overall results Fall 2011 (n=48). Pre-test mean: 64.5; Post-test mean: 62.2  **C**: Overall results Spring 2012 (n=49). Pre-test mean: 68.3; Post-test mean: 67.2
Figure 13: One-way ANOVA analysis of normalized changes in self-efficacy scores by semester. Spring 2011=11.8%; Fall 2011=-0.9%; Spring 2012=5.9%
CHAPTER 3: AN INTRODUCTORY INQUIRY-BASED GEOLOGY LAB FROM INCEPTION TO IMPLEMENTATION

A paper in preparation for submission to the Journal of Geoscience Education

Authors: Elizabeth Moss, Cinzia Cervato

ABSTRACT:

As part of a campus-wide effort to transform introductory science courses to be more engaging and to more accurately convey the excitement of discovery in science, we have re-created the curriculum of our introductory geology lab. We have transformed what was a series of ‘cookbook’ lab activities into a series of activities based in scientific inquiry and cooperative learning. We spent the first two semesters (Spring and Fall 2011) developing and implementing the new lab activities and have spent the last two semesters (Spring and Fall 2012) refining the activities. In the Fall 2011 and Spring 2012 semester we gave students enrolled in the lab a 15 question version of the Geoscience Concept Inventory (GCI, Libarkin et al., 2005) and found significant improvements from pre-test to post-test scores. This paper will present an overview of the lab activities in our new curriculum.

INTRODUCTION

As it is the case at many research universities, one-credit introductory geology labs are offered to students from all majors who need to fulfill a general education requirement that includes a lab. In our department, the lab course was decoupled from the lecture over a decade ago to accommodate for the growing enrollment in the lecture (about 500 students each semester), the lower number of Teaching Assistants (TAs) available to teach the labs, and the limitations of a single classroom dedicated to lab instruction. Enrollment in the lab course has varied between 75 and 125 students and, while geology and Earth science majors are required to
take the lab, the vast majority of students enrolled comes from a broad range of majors. The traditional approach has been to use the NAGT/AGI lab manual and select 12-14 chapters to cover throughout the semester. The format included a short lecture by the TA accompanied by a handout that assigns problems to solve in the lab manual. Ideally students would complete the worksheets in the lab with the assistance of the TA. In reality, many students would leave right after the lecture and hand in the completed worksheet at the beginning of the following lab period. This approach did not encourage group work and or the exploration of the material beyond what was included in the required set of questions. This model reinforced students’ ideas that science is boring and did not do much to increase the scientific literacy of the students involved. However, students liked this passive format: student evaluations were consistently above 4.0 on a 1-5 scale with 5 representing ‘excellent’. But what a missed opportunity! With the vast majority of students in the lab being non-STEM majors, could we really afford to waste the opportunity to truly engage them in the scientific content during the full two hours per week that the lab was scheduled for? Two years ago we decided that the answer was ‘no’ and that it was time to shift our focus onto the learner. So we changed our curriculum to focus on student engagement, cooperative learning, and scientific inquiry. In this paper we describe the results of this process.

PEDAGOGICAL BACKGROUND

Active learning strategies engage students in learning the content, instead of passively receiving it from the instructor (Handelsman et al., 2001; Arthurs and Templeton, 2009). Inquiry and cooperative learning are both examples of active learning strategies (Arthurs and Templeton,
Learner-centered teaching uses students’ existing knowledge as a basis on which to build new knowledge (Bransford et al., 2000).

The word “inquiry” is ubiquitous in science education literature, but an exact definition of inquiry is harder to come by (Windschitl, 2001; Anderson, 2002; Bruck et al., 2008). Inquiry-based education can describe both the process of teaching students how scientists use inquiry, and also having students use inquiry to learn science content (National Research Council, 1996; Colburn, 2000; Clough, 2006). Guiding definitions for our curricular reform efforts come from Weaver et al.’s (2008) and the National Research Council’s (NRC, 2000) descriptions of inquiry: inquiry is “involving students in the discovery process” (Weaver et al., 2008) and engaging students “in many of the same activities and thinking processes as scientists” (NRC, 2000). The NRC (2000) also outlines five crucial components of inquiry: 1) students engage in scientifically oriented questions, 2) students give priority to evidence in responding to questions, 3) students formulate explanations from evidence, 4) students connect explanations to scientific knowledge, and 5) students communicate and justify their explanations.

Cooperative learning is another form of active learning that we employed in this curriculum reform. Research has shown that cooperative learning strategies are effective at helping students learn science content (e.g. Yuritech et al. 2001). A common cooperative learning technique is the jigsaw activity first developed by Aronson et al. in 1978. Jigsaw activities generally start by breaking students into small groups. Each group of students learns a piece of important content (e.g., what characterizes a sedimentary rock), and as such become “experts” in that topic. For the second portion of the activity, one student from each “expert group” forms a new small group where each student is charged with conveying the material he/she learned in his/her “expert group” to the other students in the group. Once each student
has shared their content, the small group completes an application activity (e.g. identifying different types of rocks in a pile). Jigsaw activities give each student a critical role in learning and conveying information to other students in the class, keeping them engaged in learning the material (Aronson et al., 1978). As we transformed our geology labs, we relied heavily on the Jigsaw technique as a basis for structuring the lab activities.

COURSE OVERVIEW

Geology 100L is an introductory physical geology lab taught at a large US Midwestern university with a total enrollment of close to 31,000 students. The lab consists of 3-4 sections with up to 25 students meeting weekly for two hours for 15 weeks. Geology 100L is offered fall and spring semester and is taught by graduate student TAs that change from semester to semester. Approximately two-thirds of the students are non-geology majors and non-STEM majors, ranging from freshmen to seniors, and are enrolled in the class to fulfill the general education requirement for a natural science laboratory course. There is usually an even split between female and male students.

In addition to the creation of a series of inquiry labs, we also incorporated a six-week research project into the lab. This research project is detailed in a companion article also submitted to this journal (Moss et al, in prep.). In order to accommodate the research project, we needed to remove some lab topics from the course. This was a challenging process as no firm guidelines for what should be taught in college-level introductory geology labs exists locally or nationally. We conducted a survey of 32 university introductory geology lab syllabi and found some consistent patterns in what was taught, but much variety as well (Figure 1). We needed to find a balance of what should be covered at this stage for geology majors and what we felt were
the needs of the larger population of students enrolled in these labs. We eliminated labs on
glacial processes and climate change, geologic structures, earthquakes, and one of the weeks
spent on mineral identification (Table 1).

LAB ACTIVITIES: BEFORE AND AFTER

Prior to our curriculum changes, labs had the following structure: the TA would give a
brief lecture on the topic, the students would complete exercises from the lab manual, and then
leave as soon as they were finished. This format hardly engaged the students. The weekly lab
content was usually disconnected from other labs and presented as isolated units. The content
was chosen by the instructors that supervised the lab TAs each semester. Because the lab is a
separate course from the introductory lecture and students could take the lab after the lecture,
there was no effort to schedule lecture content and lab content to be covered concurrently. An
overview of the topics covered in the lab prior to our curriculum changes is shown in Table 1.

After the transformation, all labs became inquiry-based and utilized some form of the
jigsaw teaching strategy, with the intent to engage the students for the full class time. The lab
manual and TA lecturing have been eliminated. Each inquiry lab is structured so students
explore the content instead of being told about it by the TA or lab manual. Students are asked to
use observations and other evidence to answer questions during the lab, and groups are asked to
present their findings to the rest of the class. We also have sought to create a more cohesive
schedule for the labs and to build connections throughout the curriculum. For example, the rock
identification labs are a four-week series that culminates in an application activity.
Mineral and Rock Identification, and the Rock Cycle

Previously, mineral identification, the rock cycle, and rock identification were taught over five weeks. Each lab included a lecture by the TA on the topic and then hand sample identification. Two weeks were dedicated to mineral identification. Igneous, sedimentary, and metamorphic rocks were taught in three separate weeks and there was little connection between the labs.

In our revised curriculum, we removed one week of mineral identification and pared down identification to common minerals. Students begin the mineral identification lab by working in groups to create a classification scheme for 12 unknown mineral samples. There are two sets of mineral samples, set A and set B, that each contain the same 12 minerals, but the forms of some of the minerals differ between the sets (e.g., set A has specular hematite and set B has oolitic hematite, set A has calcite showing its cleavage and set B has calcite showing its crystal form, set A has milky quartz and set B has rose quartz). Groups then switch samples with another group that has the other set and test how their classification scheme works. The differing forms of minerals between the sets causes problems in some students’ self-created schemes. The groups that switched mineral sample sets compare their results and classification schemes, discussing where and why any discrepancy arose. This is then followed by a whole class discussion on the problems the students encountered, followed by a brief overview of the physical characteristics (i.e. luster, hardness, streak, etc.) geologists usually use to identify minerals and the commonly accepted classification scheme. This allows students to see the rationale behind the accepted classification scheme instead of just memorizing it. Finally, They use what they learned about how minerals are classified and identify a small selection of new mineral samples. These activities take a full lab period.
At the beginning of the second week of this series, students spend a few minutes identifying the 12 minerals from the classification activity, allowing them to review and apply what they learned the previous week. The rest of the class is spent on a rock identification jigsaw activity. Students break up into three groups and each group is assigned a different rock type (igneous, sedimentary, or metamorphic) to become “experts” on. They are given a list of concepts to describe and understand, and basic resources that provide that information. Each group presents what they have learned to the rest of class. The presentations usually occur at the end of the second week of the series, or at the beginning of the third week. After the presentations, one member of each “expert” group is placed in a new identification group of three ‘experts’ and the three students identify a selection of igneous, sedimentary, and metamorphic hand samples.

This series of labs culminates in the fourth week with a two-part activity on the rock cycle. For the first part of the lab, groups of students are given an igneous, sedimentary, and metamorphic rock and asked to describe and identify each rock, as well as identify the minerals present in the rock and match those minerals to the hand samples they saw the first week of the series. They then “transform” the rocks into a rock of a different type (e.g., transform an igneous rock into a sedimentary rock). They describe the process of how the original rock can be transformed into the new rock, and identify what rock would result from the process. For the second part of the lab, students choose a random rock and move that rock through the rock cycle, creating at least one igneous, sedimentary, and metamorphic rock. For example, a group of students could start out with gneiss and transform it to granite, then sandstone, and finally quartzite. They are again asked to describe the processes by which they change their rocks. Each group then presents their rock cycle to the rest of the class, and students are asked to
write written reflections on how each rock cycle was different and whether or not there are many paths through the rock cycle.

The revised series of labs keeps students engaged for the full class period each week and allows them to see and experience the connection between minerals, rocks, and the rock cycle. It also allows students to understand how and why classification schemes were created for rocks and minerals. This series of labs engages students in all five components of the NRC’s definition of inquiry: students seek to answer the question of how to identify minerals and rocks, use observational evidence (e.g., luster, grain size, texture) to make and support their identifications, connect their understanding of identification to current scientific identification schemes, and communicate their ideas verbally to the class at multiple steps along the way.

**Plate Tectonics and Pangaea**

The plate tectonics lab that we used to teach in the lab consisted of a series of questions that guided students through the current understanding of plate boundary location, convection, and plate tectonic theory. Students were not required to collaborate with one another as they completed the lab and were asked to focus on the location and relative amounts of the different types of plate boundaries that were given to them.

The new inquiry lab is a jigsaw activity that has been slightly modified from the “Discovering Plate Boundaries” activity created by Dale Sawyer at Rice University (Rice et al., 2005). Each group of students uses one type of physical evidence (earthquake depth and location, ocean floor age, topography, and volcano location data) to describe the patterns that they see in plate boundaries. Each “expert” group then classifies the boundaries based on these data. For example, the earthquake group might classify one type of boundary as having shallow,
sparse earthquakes, and classify another type of boundary as having numerous earthquakes that occur at increasing depth. Once the “expert” groups have classified all of the boundaries on their map, one member of each “expert” group forms a “plate group”, where they combine their data and classifications, and seek to create a new classification scheme for the boundaries. It is only after they have created their own plate boundary map that they see an “official” map. This allows students to understand what characterizes the different types of plate boundaries. Students collaborate with each other throughout the entire lab period.

The second lab in this series focuses on reconstructing the past arrangements of the continents based on geologic deposits and fossils, and uses the past location of the continents to explain the plate boundary distributions we see today. The class is divided into five groups, each receiving a map showing the present day continents with the locations of various fossils and rock formations with their ages (Table 2).

Each group uses their information to reconstruct where the continents were 250 Ma and 125 Ma. Once each group has made their reconstructions, groups 1, 2, and 3 and groups 4 and 5 get together, using the combined evidence to further refine their reconstructions. The larger groups then compile history of how the continents moved from Pangaea to where they are today. Students are asked to use their knowledge of plate tectonics and the location of different plate boundaries (developed in the previous week) as they create their history, as well as cite evidence to support their ideas. The whole class combines and students further refine and outline the history of the continents, again using evidence from the geologic record and modern-day plate boundaries to support their claims. Each student turns in a written copy of their history for credit.
Like the plate tectonics lab, students spend the entire time working in collaboration. This series of labs engages students in all five components of the NRC’s definition of inquiry; students seek to answer the questions of what distinguishes the different types of plate boundaries and what the arrangement of the continents was in the past, physical evidence to support their interpretations and reconstructions, connect their interpretations and reconstructions with a current plate boundary definitions and locations and the current model of Pangaea, and communicate their reconstructions verbally and in written form.

**Topographic Maps**

Prior to the curriculum changes, the topographic map lab questions asked students to explain the symbols used in topographic maps and answer a few basic questions about a variety of topographic maps of locations across the US. Students who live in an age where ubiquitous GPS devices provide directions, often did not see the usefulness of understanding how to read a map, causing many of them to find this activity irrelevant.

Instead of using maps from various parts of the country, the inquiry lab uses local maps to teach the students the same concepts that were covered originally. First, students map the extent of the 2010 flood in the city of Ames (Iowa), and then create a contour map of a nearby State Park and map the extent of the 2010 flooding in that area.

The first part of the lab begins with pairs of students exploring and familiarizing themselves with the USGS topographic map of the Ames area for five minutes. Students are then asked to point out and describe the basic features of the map (e.g., the scale of the map). Students are then shown the 2010 peak stage level of the South Skunk River, a river that crosses the city; the stage was measured at a USGS stream gage just south of the city. Students
are asked to map the areas affected by the flood on tracing paper. Students compare their maps with the ones produced by other groups in the class.

In the second part of the lab, students create a contour map of a nearby State Park where the students were taken on a 3-hour field trip a few weeks beforehand. During the field trip, students took GPS measurements at various places using a handheld GPS device and recording a description of where each measurement was taken. The GPS locations were compiled and used to create a map using ArcGIS. Using the elevation of each point, students make a contour map of the park. Using this map, students mark what areas of the park would be affected by different flood stages, including mapping the areas affected by the 2010 flood. Students then compare their contour and flood maps with a map created in GIS by the TA.

This activity puts the learning into a local context, utilizing placed-based learning to effectively teach the students the content (Lieberman and Hoody, 1998). The activities also serve as a relevant application for understanding and using topographic maps. This is the only lab in our revised curriculum that does not employ some form of the jigsaw model, though students do complete the exercise in groups. In this lab, students engage in the five components of the NRC’s definition of inquiry when they answer the question of how to determine what areas were affected by a recent flood, use physical evidence to answer and support their conclusions, compare their maps with maps of the areas affected by the flooding, and share their maps with the class.

**Time Activity**

The last lab activity of the semester focuses on geologic time, a concept often hard for students to grasp (Dodick and Orion, 2003; Libarkin et al., 2007). This lab was originally
focused on students understanding relative and absolute dating methods, and having students apply these methods to date cartoon and photographs of stratigraphic sections. At no point students were asked to conceptualize the vast amount of time in geologic history.

The new inquiry lab focuses on applying relative and absolute dating measurements to rock and fossil samples representative of the history and stratigraphy of Iowa, as well as mapping out the extent of geologic time. The lab begins with an activity that uses pennies to teach the concept of radioactive decay. Pairs of students are given a set of 20 pennies and told that the heads side of the penny represents the parent isotope and the tails side the daughter isotope. Initially, all of the pennies are heads up, representing a 100% composition of the parent isotope. The instructor leads the students through a series of “half-lives,” where students toss the pennies in the air and drop them onto the table. Each penny that lands heads up represents a parent isotope and each penny that lands tails up represents an atom that has decayed into the daughter isotope. Each pair counts the number of heads and tails, and the class graphs the total amounts on the board. Daughter isotopes, or pennies that were tails up, are removed before the students repeat the same process for four or five “half-lives”. This exercise generally models decay accurately and also elucidates why radiometric dating becomes less effective when very small proportions of the parent isotope remain.

After the introduction to radiometric dating, students begin an activity that asks them to reconstruct the local geologic history using two series of hand samples (hand samples are representative of local geology, but not necessarily from the area). Each student is assigned a role as one of five different geoscientist specialists (geochronologist, petrologist, paleontologist, paleoclimatologist, and stratigrapher) and is provided with different information and tasks in identifying the samples. Each student does not have information for every sample, but the group
must work as a whole to understand the samples. Geochronologists are given the ratio of parent-daughter isotopes and are asked to calculate the age of some of the samples. Petrologists are asked to use their experience with rock identification to identify some of the samples. Paleontologists are given an overview of various types of fossils they might encounter and are asked to identify different fossil samples. Paleoclimatologists are given background information on what types of rocks form in different climate areas and are asked to identify the environment in which the fossil or rock was deposited. Stratigraphers are tasked with combining all of the groups’ information and ordering the samples from oldest to youngest. After the group identifies the two series of samples (one focusing on the shallow marine history of the area and the other focusing on the most recent glaciation of the area), they write out a history of the area, using evidence to support their conclusions. Students are then presented with short summaries of the accepted geologic history of the area.

To end the lab period, students draw a geologic time scale with chalk on the lab tables using one millimeter to represent one million years. They mark the geologic period (provided) on their scales, and mark where the samples from the history activity fall. They are also given small figurines of different life forms (e.g., brachiopods, horses, different dinosaurs) and asked to place those on the timeline. This activity allows them to visualize the geologic time scale, as well as the relatively small proportion of that geologic time scale that life has been present on earth.

As students reconstruct portions of the geologic history of Iowa using fossil and rock evidence, communicate their conclusions through writing, and compare their conclusions with the history that is accepted by the geologic community, they are engaging in the five components
of the NRC’s definition of inquiry. The lesson plan and student handouts for this lab can be found in Appendix E.

ASSESSMENT

Observations of students in the class show that they are engaged for the majority of the class period, a successful change from the previous curriculum, and are all spending the full lab period working in class. Students actively collaborate for every lab activity. Each activity allows students to engage in scientific inquiry in a fun way. Anecdotal comments from students in course evaluations suggest that the students enjoy the labs.

Since so many variables have changed from before the reform and after (e.g., TA, quiz content, grading scale), it would be meaningless to compare the final lab grade, before and after the transformation. Instead, in the Fall 2011 and Spring 2012 semesters we used a 15-question subset of the Geoscience Concept Inventory (GCI) (Libarkin and Anderson, 2005) to measure change in conceptual understanding in the students. This is the same subset used to assess learning in introductory labs at North Carolina State University (McConnell, 2011, personal communication) and focuses on plate tectonics and geologic time (Appendix C). Previous studies that have used the GCI found that the majority of introductory courses do not produce significant gains in student understanding by the end of the semester (Libarkin and Anderson, 2005; McConnell, 2009). McConnell et al. (2006) found that research supported teaching practices more consistently produced gains in students’ conceptual understanding than traditional lecture courses. In courses where students are making gains, they are on the order of an increase of one more correct question on the instrument (Libarkin and Anderson, 2005). McConnell
(2009) suggests that normalized gains of 10-20% are realistic and desirable for introductory courses.

Using a One-way ANOVA on our data, we found that there was a significant increase in students’ scores from the pre-test to the post-test in both semesters (Figure 2). This increase was equivalent to an increase of one more correct answer on the post-test than the pre-test, consistent with what has been observed by Libarkin and Anderson (2005). Additionally, normalized gains for our data were 18.8% and 17.6% for the Fall 2011 and Spring 2012 semesters (Figure 3). These are within the targeted range of improvement for an introductory course according to McConnell (2009). The GCI subset we used does not cover many of the other topics covered in the course, including groundwater and surface water, which are topics extensively studied through the research project. However, plate tectonics and geologic age are covered in the course, and the new curriculum is effective at improving students’ understanding of these concepts.

**CHALLENGES**

Possibly the biggest challenge in implementing this style of lab is to ensure the TAs buy-in into the new concept and to train them in inquiry-based teaching. Some TAs believe that it is easier and less time-consuming to prepare a short lecture and assign students questions instead of engaging them for two hours. The questions that students ask during inquiry activities are not predictable, and can thus be intimidating for the graduate and undergraduate TAs who themselves have only a few years more experience than the students they teach in the lab. We have found that having a pre-semester training and weekly meetings with the TAs to discuss how the lab went and discuss the plan for the upcoming lab, helps them feel more comfortable
teaching the inquiry labs. We have also created lesson plans for each lab, outlining what materials are needed, approximate times for each activity, and possible questions students might ask, or questions that the TA might want to ask the students. Additionally, one TA is tasked with lab coordination and is in charge of preparing all of the materials needed.

Transforming our introductory geology lab from “cookbook” labs to inquiry and jigsaw labs has been a gradual and on-going process. After four semesters of implementation, we are still making tweaks and changes in the lab activities. In the first semester (Spring 2011), we revised about half of the labs and left some as they had been taught for years (Table 1). Starting in Fall 2011 all of the labs were inquiry-based and we have been making small adjustments at every new implementation. While it may be possible to completely overhaul a curriculum in one semester, we found that making the transition more gradual helped reduce TA anxiety.

CONCLUSIONS

We have successfully transformed the curriculum of Geology 100L into a learner-centered, inquiry based lab. Instead of a “cookbook” activity, each lab engages students in collaboration for the majority of the class period, asking them to investigate physical evidence in order to understand and explain basic geologic concepts. This new curriculum is positively impacting students understanding of geologic concepts. As we move forward using the new curriculum, we will continue to refine the activities. We also plan to create a course packet that contains the background materials and in-class activities for students to use.

Acknowledgements:

We would like to thank Tom Parham, Sarah Day, and Joe Kohlhaas for their help in developing these lab activities, as well as Angela Zhang and Stephen Bergson for help compiling
the syllabi data. Thank you also to the TAs who patiently worked through the rough spots in the curriculum. This project was funded by the Howard Hughes Medical Institute.

REFERENCES


Table 1: An example of the weekly lab schedule before, during and after changes to the curriculum. Classes devoted to the research project (Moss et al, in prep) are in bold font and inquiry based labs are shown in red.

<table>
<thead>
<tr>
<th>Week</th>
<th>Before</th>
<th>Spring 2011</th>
<th>Fall 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction to measurements and earth processes</td>
<td>Introduction + NOS tubes activity</td>
<td>Introduction + NOS tubes activity</td>
</tr>
<tr>
<td>2</td>
<td>Plate Tectonics</td>
<td>Plate Tectonics (from Lab Manual)</td>
<td>Introductory Field Activity</td>
</tr>
<tr>
<td>3</td>
<td>Earthquakes</td>
<td>Earthquakes (from Lab manual, with additional data)</td>
<td>Streams and Groundwater (practice investigation)</td>
</tr>
<tr>
<td>4</td>
<td>Mineral Identification</td>
<td>Streams and Groundwater (investigation about flooding)</td>
<td>Streams and Groundwater (practice investigation)</td>
</tr>
<tr>
<td>5</td>
<td>Mineral Identification</td>
<td>Streams and Groundwater (investigation about flooding)</td>
<td>Mineral Identification</td>
</tr>
<tr>
<td>6</td>
<td>The Rock Cycle + Igneous Rocks</td>
<td>Rock Cycle (using chocolate as a model)</td>
<td>Rock Identification</td>
</tr>
<tr>
<td>7</td>
<td>Sedimentary Rocks</td>
<td>Rock and Mineral Jigsaw</td>
<td>Rock Identification</td>
</tr>
<tr>
<td>8</td>
<td>Metamorphic Rocks</td>
<td>Rock and Mineral Jigsaw</td>
<td>Rock Cycle</td>
</tr>
<tr>
<td>9</td>
<td>Geologic Time</td>
<td>Rock and Mineral Jigsaw</td>
<td>Field Day</td>
</tr>
<tr>
<td>10</td>
<td>Stream Processes</td>
<td>Spring Break</td>
<td>Plate Tectonics</td>
</tr>
<tr>
<td>11</td>
<td>Groundwater Processes</td>
<td>Glaciers and Climate Change (from Lab manual)</td>
<td>Pangea</td>
</tr>
<tr>
<td>12</td>
<td>Geologic Structures and Maps</td>
<td>Geologic Structures (Paper folds)</td>
<td>Work Day</td>
</tr>
<tr>
<td>13</td>
<td>Topographic Maps</td>
<td>Geologic Time</td>
<td>Topographic Maps</td>
</tr>
<tr>
<td>14</td>
<td>Thanksgiving Break</td>
<td>Work Day</td>
<td>Thanksgiving Break</td>
</tr>
<tr>
<td>15</td>
<td>Glacial Processes and Climate Change</td>
<td>Work Day</td>
<td>Poster Presentations + Virtual Volcano Activity</td>
</tr>
<tr>
<td>16</td>
<td>Quiz</td>
<td>Work Day</td>
<td>Geologic Time + Capstone Activity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Poster Presentations</td>
<td></td>
</tr>
</tbody>
</table>
Table 2: Fossil and rock evidence for different groups in the Pangaea reconstruction activity.

<table>
<thead>
<tr>
<th>Group</th>
<th>Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cynognathus and glossopteris fossils</td>
</tr>
<tr>
<td>2</td>
<td>Mesosaurus and lystrosaurus fossils</td>
</tr>
<tr>
<td>2</td>
<td>Nothofagus tree fossils; the location of the Appalachian mountain belt in the United States and Europe</td>
</tr>
<tr>
<td>4</td>
<td>Ancient and modern day coal deposits</td>
</tr>
<tr>
<td>5</td>
<td>Evidence of ancient glaciation</td>
</tr>
</tbody>
</table>
**Figure 1:** Frequency of topics covered in a survey of 32 introductory geology lab syllabi.

**Occurrence of Courses**

- Sedimentary rocks: 32
- Igneous Rocks: 32
- Minerals: 32
- Metamorphic rocks: 31
- Land navigation & topographic maps: 26
- Geologic Hazards: 19
- Geologic Time: 19
- Field trips: 17
- River landscapes and flooding: 16
- Geologic structures: 14
- Desert and glacial landscapes: 13
- Groundwater: 11
- Plate tectonics: 11
- Oceans and Shorelines: 9
- Carbon footprint/Energy use: 6
- Weathering and Erosion: 5
- Soil: 5
- Rock Cycle: 3
- Rain: 3
- Region Specific: 3
- Climate: 2
- Geophysics: 2
- Waterfall: 1
Figure 2: Oneway ANOVA analysis of total scores on the GCI for students enrolled in Geology 100L. **Fall 2011:** n=49. Pre-test mean=7.9, Post-test mean=9.2, p=0.007. **Spring 2012:** n=33. Pre-test mean=8.2, Post-test mean=9.8, p=0.003.
Figure 3: Oneway ANOVA analysis of normalized gains for the GCI. Fall 2011: Normalized gains: 18.8%. Spring 2012: Normalized gains: 17.6%.
CHAPTER 4: GENERAL CONCLUSIONS

We have successfully incorporated an authentic research project and inquiry-based lab activities into the Geology 100L curriculum over the course of the past four semesters. Though these changes to the curriculum have not caused tangible improvements in NOS understanding and science SE, the changes are still improvements to the course. Students are now engaged in learning for the majority of the class time, learn content in a way that reflects how students learn, and have an opportunity to explore the local environment through the research project. The new curriculum has also been shown to be effective at increasing students’ understanding of plate tectonics and geologic time. Though the changes to the Geology 100L curriculum alone may not dramatically impact the STEM enrollment rates at Iowa State University, as a part of a whole, they have the potential to build interest in science among students at Iowa State University.
ACKNOWLEDGEMENTS

This thesis is dedicated to my father, Ted Boal. You have instilled within me a passion and curiosity to understand the world around me. I am the woman and scientist I am today because of you. I love you.

My time in graduate school has been a time of growth both as a researcher and as a disciple of Christ. I have been blessed to be surrounded by innumerable supporters throughout this journey. I cannot name every person who has influenced me, but will highlight a few.

Cinzia: Thank you for inviting me to join you on this journey. I have enjoyed diving into the world of geoscience education with you. Thank you for opening a door to a place I have found to be my niche. Thank you also for your generosity and support along the way.

Bill and Craig: Thank you for serving on my committee, providing wonderful feedback, and paving a way for this project to come to fruition. You both played crucial roles in accomplishing this project!

Tom, Rachel, Shelly and Jake: I would not have made it through this process without your wisdom, perspective, and encouragement. Thank you for supporting me from day one.

Thanks to all the other geology graduate students and faculty who have made my time in the department fun and enriching.
Jacob: You are such a good gift from the Lord! Thank you for supporting me through the highs and lows, encouraging me to press on, and spurring me on to run hard for what matters. You are irreplaceable. I am delighted to spend the rest of my life with you!

Family: Thanks for making me who I am! I am absolutely blessed to belong to all of you, and delighted that we share a passion for the Lord. Thank you also to the Moss clan for welcoming me into your family--you are also a delight!

To my women: You refresh my soul! Thank you for sharing your lives and hearts with me. Thank you for helping me grow and pointing me back to Christ. Thanks for listening, sharing truth, and comforting me when I needed it.

To the saints in Ames: Thank you for running with me, challenging me by living lives devoted to Christ, and being a second family.

I will close with the trademark of Bach: Soli deo gloira. I claim no wisdom, skill, or insight apart from what the LORD has blessed me with. I am but a jar of clay, broken and weak, as a glorious display of His power, love, and grace.
APPENDIX A: SUSSI INSTRUMENT

Views on Science and Scientific Inquiry

Please read EACH statement carefully, and then indicate the degree to which you agree or disagree with EACH statement by circling the appropriate choice to the right of each statement.

SD = Strongly Disagree  
D = Disagree More Than Agree  
U = Uncertain or Not Sure  
A = Agree More Than Disagree  
SA = Strongly Agree

1. Scientific Observations

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<tr>
<th></th>
<th>Statement</th>
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<th>D</th>
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<th>SA</th>
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<tbody>
<tr>
<td>A</td>
<td>Scientists’ observations of the same event may be different because the scientists’ prior knowledge may affect their observations.</td>
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<td>B</td>
<td>Scientists’ observations of the same event will be the same because scientists are unbiased.</td>
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<tr>
<td>C</td>
<td>Scientists’ observations of the same event will be the same because observations are facts.</td>
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<tr>
<td>D</td>
<td>Scientists may make different interpretations based on the same observations.</td>
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Explain why you think scientists’ observations and interpretations are the same OR different, and provide examples to support your answer.

2. Social and Cultural Influences on Science

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<tbody>
<tr>
<td>A</td>
<td>Scientific research is not influenced by society and culture because scientists are trained to conduct pure, unbiased studies.</td>
<td></td>
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<td>B</td>
<td>Cultural values and expectations influence what science is conducted and accepted.</td>
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<tr>
<td>C</td>
<td>Cultural values and expectations influence how science is conducted and accepted.</td>
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<tr>
<td>D</td>
<td>All cultures conduct scientific research the same way because science is universal and independent of society and culture.</td>
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Explain how society and culture affect OR do not affect scientific research, and provide examples to support your answer.
3. Imagination and Creativity in Scientific Investigations

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<tbody>
<tr>
<td>A.</td>
<td>Scientists use their imagination and creativity when they collect data.</td>
<td>SD</td>
<td>D</td>
<td>U</td>
<td>A</td>
</tr>
<tr>
<td>B.</td>
<td>Scientists use their imagination and creativity when they analyze and interpret data.</td>
<td>SD</td>
<td>D</td>
<td>U</td>
<td>A</td>
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<tr>
<td>C.</td>
<td>Scientists do not use their imagination and creativity because these conflict with their logical reasoning.</td>
<td>SD</td>
<td>D</td>
<td>U</td>
<td>A</td>
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<tr>
<td>D.</td>
<td>Scientists do not use their imagination and creativity because these can interfere with the need to be unbiased.</td>
<td>SD</td>
<td>D</td>
<td>U</td>
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Explain why scientists use OR do not use imagination and creativity, and provide examples to support your answer.

4. Methodology of Scientific Investigations

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<tr>
<td>A.</td>
<td>Considering what scientists actually do, there really is no such thing as the scientific method.</td>
<td>SD</td>
<td>D</td>
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<td>A</td>
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<tr>
<td>B.</td>
<td>Scientists follow the same step-by-step scientific method.</td>
<td>SD</td>
<td>D</td>
<td>U</td>
<td>A</td>
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<tr>
<td>C.</td>
<td>When scientists use the scientific method correctly, their results are true and accurate.</td>
<td>SD</td>
<td>D</td>
<td>U</td>
<td>A</td>
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<tr>
<td>D.</td>
<td>Experiments are the only way scientists develop valid scientific knowledge when they investigate the natural world.</td>
<td>SD</td>
<td>D</td>
<td>U</td>
<td>A</td>
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Explain whether scientists follow a single, universal scientific method OR use different types of methods, and provide examples to support your answer.
5. Social Interaction among Scientific Researchers

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<tbody>
<tr>
<td>A. Scientists usually work collaboratively with other scientists when conducting research.</td>
<td>SD</td>
<td>D</td>
<td>U</td>
<td>A</td>
</tr>
<tr>
<td>B. Scientists usually work with other scientists, but only to share results.</td>
<td>SD</td>
<td>D</td>
<td>U</td>
<td>A</td>
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<tr>
<td>C. Scientists usually work alone when conducting research.</td>
<td>SD</td>
<td>D</td>
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<tr>
<td>D. Scientific knowledge usually emerges from discussions and social interactions among scientists.</td>
<td>SD</td>
<td>D</td>
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Explain to what degree scientists work with other scientists when doing research, and provide examples to support your answer.

6. Development and Acceptance of Science Ideas

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<tr>
<td>A. Credible scientific ideas are usually generated in a matter of days, weeks or months.</td>
<td>SD</td>
<td>D</td>
<td>U</td>
<td>A</td>
</tr>
<tr>
<td>B. Scientific ideas usually come to be accepted by the scientific community in a matter of days, weeks or months.</td>
<td>SD</td>
<td>D</td>
<td>U</td>
<td>A</td>
</tr>
<tr>
<td>C. Credible scientific ideas are usually generated over a period of years to decades.</td>
<td>SD</td>
<td>D</td>
<td>U</td>
<td>A</td>
</tr>
<tr>
<td>D. Scientific ideas usually come to be accepted by the scientific community over a period of years to decades.</td>
<td>SD</td>
<td>D</td>
<td>U</td>
<td>A</td>
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Explain how much time is usually required for credible scientific ideas to be generated, and then accepted by the scientific community, and provide examples to support your answer.
7. Scientific Knowledge

A. Well supported and established scientific knowledge is subject to ongoing testing and revision.

B. Well supported and established scientific knowledge may be completely replaced by new ideas in light of new evidence.

C. Well supported and established scientific knowledge may be changed because scientists reinterpret existing evidence.

D. Well supported and established scientific knowledge based on accurate research will not change.

Explain why you think well supported and established scientific knowledge changes OR does not change over time, and provide examples to support your answer.

8. Discovery and Invention

In responding to the four items below, assume that a gold miner "discovers" gold while an author "invents" a story.

A. Scientific theories (for example, atomic theory, plate-tectonic theory, gene theory) are discovered.

B. Scientific laws (for example, laws of planetary motion, gas laws, gravitational law, law of pendulum motion) are discovered.

C. Scientific theories (for example, atomic theory, plate-tectonic theory, gene theory) are invented.

D. Scientific laws (for example, laws of planetary motion, gas laws, gravitational law, law of pendulum motion) are invented.

Explain whether scientific laws and theories are invented OR discovered, and provide examples to support your answer.
APPENDIX B: SELF-EFFICACY INSTRUMENT

On a scale from 1 to 10, 1 being "not able or not true at all" and 10 being "completely able or completely true," rate your answer to the following questions.

1. I have confidence in my ability to do science.
2. There are some tasks required by being a scientist that I cannot do well.
3. When my performance in science is poor, it is due to my lack of ability.
4. I doubt my ability to do science.
5. I have all the skills needed to perform science tasks very well.
6. Most people in my field can do science better than I can.
7. I am an expert at doing science.
8. My future in science is limited because of my lack of skills.
9. I am very proud of my science skills and abilities.
10. I feel threatened when others watch me work.
APPENDIX C: GEOSCIENCE CONCEPT INVENTORY

GEOSCIENCE CONCEPT INVENTORY TEST QUESTIONS
Please answer the following questions to the best of your ability using the bubble sheet provided. Use only a #2 pencil. Enter your name and ISU ID# (the middle nine digits) in the left part of the bubble sheet.

1. Is this a pretest (at the beginning of the semester) or post-test (at the end of the semester)
   (A) Pre-test
   (B) Post-test

2. What is your academic rank?
   (A) Freshman
   (B) Sophomore
   (C) Junior
   (D) Senior
   (E) Graduate student

3. In which lab are you currently enrolled?
   (A) Geology 100L
   (B) Geology 201
   (C) Geology 106L

4. What does "density" refer to?
   (A) How big something is
   (B) How quickly particles move
   (C) How much material exists in a space
   (D) How much air is contained in an object
   (E) How slowly liquids move

5. Scientists claim that they can determine when the Earth first formed as a planet. Which technique(s) do scientists use today to determine when the Earth first formed? **Mark all that apply.**
   (A) Comparison of fossils found in rocks
(B) Comparison of layers found in rocks
(C) Analysis of uranium found in rocks
(D) Analysis of carbon found in rocks
(E) Scientists cannot calculate the age of the Earth

6. What did the Earth's surface look like when it first formed?
7. Some people believe there was once a single continent on Earth. Which of the following statements best describes what happened to this continent?

(A) Meteors hit the Earth, causing the continent to break into smaller pieces
(B) The Earth lost heat over time, causing the continent to break into smaller pieces
(C) Material beneath the continent moved, causing the continent to break into smaller pieces
(D) The Earth gained heat over time, causing the continent to break into smaller pieces
(E) The continents have always been in roughly the same place as they are today

8. Scientists often talk about the Earth’s tectonic plates and their role in mountain formation, volcanism, and earthquake occurrence. Which of the following figures most closely represents the location of the Earth’s tectonic plates?

- [Diagram A]
- [Diagram B]
- [Diagram C]
- [Diagram D]
9. What is the best explanation of the movement of tectonic plates?

(A) Lava moves the tectonic plates
(B) Currents in the ocean move the tectonic plates
(C) Earthquakes move the tectonic plates
(D) Gravity moves the tectonic plates
(E) Magnetism moves the tectonic plates
10. Which of the following figures do you believe is most closely related to what you might see if you could cut the Earth in half?
11. The following maps show the position of the Earth’s continents and oceans. The ● ‘s on each map mark the locations where volcanic eruptions occur on land. Which map do you think most closely represents the places where these volcanoes are typically observed?
12. Which of the following responses best summarizes the relationship between volcanoes, large earthquakes, and tectonic plates?

(A) Volcanoes typically occur on islands, earthquakes typically occur on continents, and both occur near tectonic plates

(B) Volcanoes and large earthquakes both typically occur along the edges of tectonic plates

(C) Volcanoes typically occur in the center of tectonic plates and large earthquakes typically occur along the edges of tectonic plates

(D) Volcanoes and large earthquakes both typically occur in warm climates

(E) Volcanoes, large earthquakes, and tectonic plates are not related, and each can occur in different places

13. The map below shows the position of the Earth’s continents and oceans today. The gray areas represent land, and the white represents water. Which of the following best explains why the ocean basins look the way they do?

(A) Meteor impacts caused the ocean basins to form this way

(B) Continents moving caused the ocean basins to form this way

(C) The Earth cooling caused the ocean basins to form this way

(D) The Earth warming caused the ocean basins to form this way

14. How far do you think continents move in a single year?

(A) A few inches

(B) A few hundred feet

(C) A few miles

(D) We have no way of knowing
Continents do not move

15. Some people believe there was once a single continent on Earth. If this single continent did exist, how long did it take for the single continent to break apart and form the arrangement of continents we see today?

(A) Hundreds of years
(B) Thousands of years
(C) Millions of years
(D) Billions of years
(E) It is impossible to tell how long the break up would have taken

16. Which of the figures below do you think most closely represents changes in life on Earth over time?
17. Which of the following can greatly affect erosion rates? **Mark all that apply.**

A) Rock type  
B) Earthquakes  
C) Time  
D) Climate  

18. The sketches below represent the outlines of two mountains made up of the same type of rock. The mountains have finished growing. Which of the following reasons best explains the differences in the two sketches?

A) Mountain I is older than Mountain II  
B) Mountain II is older than Mountain I  
C) Mountain I is on a continent that is moving faster than the continent Mountain II is on  
D) Mountain I is on a continent that is moving slower than the continent Mountain II is on  
E) Mountain I has experienced more erosion than Mountain II
APPENDIX D: SUSSI SHORT ANSWER GRADING SUMMARY

SUSSI Short Answer Grading Summary

Short answer responses from students were analyzed to determine whether or not they were consistent with the Likert responses. The purpose of this check was to determine whether or not the Likert responses were viable data for quantitative analysis. Previous users of the SUSSI (Miller, Liang), including the original author also graded the short answer responses as naive, transitional, or informed. For our purposes, we limited our analysis to “Consistent” or “Not consistent,” a method used by Liang et al in the original creation of the SUSSI. A detailed explanation of the “rubric” the evaluators created and used is described below. It should be noted that the short answer responses were graded on the consistency in regards to the topics that the students addressed. If a student did not address a specific statement in their short answer response, the short answer response could still be graded as consistent if what the students did address matched their Likert scores. In some cases, patterns were observed in Likert responses, and statements were clumped together (ie students answered similarly to groups of statements in the question set), such that if a student addressed one statement in their short answer but not others, the statement was graded as consistent.

Scientific Observations:
The evaluators noticed three separate ideas within this question set. Statements A and D generally address whether or not scientists can make different observations or interpretations. Statement B addressed whether or not scientists are unbiased. Statement C addressed whether or not observations are facts. The presence of three separate ideas was noticed in students’ Likert responses. For example, in the student response set shown below, a student scored 4, 2, 5 and 5 on the Likert responses for this category. Present in the short answer response was an explanation that supported their belief that scientists are unbiased (“observation is objective”), while also supporting their views that scientists may make different interpretations based on the same observations (“interpretation is subjective”). The students response did not address specifically how prior knowledge may or may not affect scientist’s observations and did not address whether or not observations were facts, but what was written agreed with points B and D, and therefore the short answer was scored as “Consistent.”

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<tr>
<td>observation is objective, for example, some people would say that a dinosaur is eating leaves. interpretation is subjective. for example, they would say that the dinosaur is eating leaves because it wants to learn how to fly, which makes no sense. or, another scientist has a different opinion.</td>
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Social and Cultural Influences:
The evaluators noticed two distinct ideas present in this question set. Statement A addresses whether or not scientists are unbiased. Statements B, C, and D address the influence of society and culture on scientific practice. In the example below, the student was unsure of whether or
not scientists were unbiased (not addressed in the short answer response), but recognized that society and culture influence how and what science is conducted and accepted, as well as that science is practiced differently in different cultures (“research is somewhat affected by the people they live by, the government ruling over them, and the values/beliefs”). This short answer was deemed “Consistent.”

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<tr>
<td>Various cultures have different beliefs about right from wrong. And each scientist lives within a specific culture. Therefore, their research is somewhat affected by the people they live by, the government ruling over them, and the values/beliefs. For example, scientific research within psychology is very much regulated by society because psychologists are dealing with human participants. There are a lot of rights and regulations protecting the people in the studies.</td>
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Imagination and Creativity in Scientific Investigations:
While the evaluators did not think any of the statements in this category stood out as distinct, they did notice that students held more strongly to the idea that imagination and creativity conflict with logical reasoning. It is unclear to the evaluators why students hold on to this idea while moving toward more informed views regarding other aspects of imagination and creativity. Because of the distinction, if the Likert scores of A, B, and D were similar, but the Likert response for statement C was different, the evaluators would rate the statement as “Consistent.” Statement D discusses whether or not imagination and creativity interfere with the need to be unbiased. Students’ Likert responses could be based on two separate issues: they could think that scientists do not need to be unbiased, or they could think that imagination and creativity do not conflict with this need. Based on the students’ responses to previous questions addressing scientists’ biases, the evaluators tend to interpret it as meaning that imagination and creativity do not interfere with this need. Many students do not address this specific statement in their short answer responses. The example below was scored as “Consistent” because the short answer addressed the need for imagination and creativity in forming hypotheses and interpreting data. The second sentence appears to address a need for scientists to be unbiased (consistent with the Likert response). Statements A was not necessarily addressed in the short answer, but was ranked on the Likert scale similarly to statement B, so it is believed that was consistent. Statement C is not addressed in the short answer, and is distinct from the other Likert responses. The evaluators believe some other factor is at play in students’ thinking in this statement, so the short answer was still graded “consistent.”

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<tr>
<td>Scientists use their imagination and creativity because it takes a lot of creative thought to come up with hypotheses or ideas for why certain things occur in nature. Scientists must be open to all ideas in order to</td>
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understand their natural surroundings. For example, it took creative thought to come to understanding how the continents formed.

Methodology of Scientific Investigation:
The evaluators noticed that each of the four statements in this category seemed to address different NOS ideas. Statement A intends to address whether or not a universal, step-by-step scientific method exists. However, analysis of short answer responses suggests that students interpret this statement differently. It appears that students read the statement as “Considering what scientists actually do, there is no such thing as scientific protocols.” Many students disagree with the original statement but justify themselves by saying that scientists follow protocols. Students explain their answers to Statement B by discussing whether or not scientists always follow the same steps in the same order. Many suggest that a scientist’s path is not linear and often involves repeating a step more than once. It should be noted that the non-linearity of how scientists generate knowledge was emphasized in the course. In the first round of evaluations, Likert data from statement C was not available. Statement D address whether or not experiments are the only way to develop valid scientific knowledge.

Both examples below show students whose written responses suggest that they think that scientists have the freedom to alter the “scientific method,” but still follow some set of general guidelines for conducting research, which is consistent with their Likert responses to statements A and B. Neither student explicitly addresses experimentation in their answer, though the second student’s examples of conducting surveys and measuring the age of the earth’s crust both suggest some form of experiment. Both student responses were graded as consistent because what was addressed in their short answer response agreed with their Likert responses.

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<tr>
<td>Sciences use the scientific method as a basic method to do research, but sometimes they have to switch it up and do different parts at different times in their research process.</td>
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<tbody>
<tr>
<td>Each scientist develops a hypothesis and begins to test it but the order they perform their methods in will not be same. A scientist conducting surveys will not go through the same steps as a scientist measuring crust age.</td>
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Social Interaction among Scientific Researchers:
The evaluators did not notice any patterns or separate misconceptions present in this section. Students generally responded similarly to all statements. However, many students responded “uncertain” to one or more Likert statements while maintaining a pattern in the other Likert statements. It is possible that the word “usually” was confusing to the students. The first response set is an example of a student who asserted that they thought scientists usually collaborated but were unsure beyond their personal experience. This pattern can be seen in the Likert responses--Statements A, B, and C all were 4’s or 5’s while the student responded “Uncertain or Not Sure” to statement D. Because the student expressed in their short answer and
Likert responses a general agreement that scientists collaborate as well as uncertainty as if that was the norm, this statement was scored as “Consistent.”

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4 5 4 3 y
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from my experience, scientists usually work collaboratively but i am uncertain as to what actually happens in outside of my personal experiences.

The second response set is an example of a grading method that the evaluators used. If students responded “Uncertain or Not Sure” to all but one statement, the agreement was based on the one statement that was not “Uncertain or Not Sure.” Here, the student’s short answer suggests that they think that ideally scientists would work together, but are unsure of whether or not the realities of funding make that possible. This was scored as “consistent” because the student expressed uncertainty as to what usually occurred (matched in Likert responses to A, C, and D) and also the thought that scientists would collaborate when possible (matched in Likert response B).

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It would seem that while doing research, multiple scientists working together would cut down on the possible errors as well as provide alternative solutions. However, funding may not provide for multiple people to work on ONE project.

The third response set is an example of a student response that was graded as “Not Consistent.” This statement was graded as “Not consistent” because the Likert responses contradict one another, and a contradictory viewpoint is not expressed in the short answer response. The short answer response suggests that the student thinks that scientists share their knowledge, which is supported in their responses to statement B and D. However, the student disagreed that scientists usually work collaboratively with other scientists when conducting research (Likert statement A) AND disagreed that scientists usually work alone when conducting research (Likert statement C). It is unclear from their written responses how this dichotomy is worked out in their mind, so this responses was graded “Not consistent.”

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2 2 5 5 n
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Knowledge must be placed in a social pool so that it can be compared with prior known information to see how it fares.

Development and Acceptance of Science Ideas:
In the original construction of the instrument, statements A and C were intended to be contradictory and statements B and D were intended to be contradictory. Generally, students respond according to that intention; however, some students do not. Those who justify their answer in their short answer response by saying that both are true are marked as consistent. The first student response set is an example of such. In the Likert section, the student agreed that credible scientific ideas were usually generated in a matter of days, weeks or months AND strongly agreed that credible scientific ideas are usually generated over a period of years to
decades. While these seem contradictory, the student addressed this idea in their short answer. It appears that the student thinks that the idea itself can be developed quickly (“in the span of a few seconds”), but the acceptance and full development of the idea takes much longer. Because the student addressed their seemingly contradictory view in the short answer section, this response set was graded as “Consistent.”

A student response set was graded as “Not consistent” because the short answer response did not seem to address any of the Likert statements. The short answer suggests the student thinks that credible scientific ideas are based on “reliable evidence that can be re-created.” However, the Likert statements in this category address how long it takes for credible scientific ideas to be generated, not what credible scientific ideas are based on. It could be inferred that the student thinks that reliable evidence takes years or decades to be collected and “re-created,” but this is not explicitly addressed in the short-answer response, so the evaluators graded this response set as “Not consistent.”

### Scientific Knowledge:

Students generally responded similarly to statements A, B, and C, but would sometimes respond differently to statement D. The evaluators believe that this pattern lies in students understanding that scientific knowledge can change, but at some point, something can be absolutely proven. This misconception is also present in the Methodology of Scientific Investigations statement C, answer to which were not available in the first round of evaluations.

The first student response set is an example of this pattern. This student response set was graded as “Consistent,” despite the anomalous response to statement D. The student’s short answer response suggests that they do believe that scientific knowledge can change with new evidence (consistent with statement B). Though they do not specifically address whether or not things can be “proven” true in their answer, the evaluators believed the student still held misconceptions in this area, and thus deemed the response “Consistent.”

The second student response set was graded as “Not consistent” because the short answer response was not consistent with their response to Likert statement B. The student’s Likert responses suggest that they think that scientific knowledge is subject to ongoing testing and
revision (statement A), can be changed because scientists reinterpret existing evidence (statement C), and can change even if it is based on accurate research (statement D) but do not think that scientific knowledge can be completely replaced by new ideas in light of new evidence. The student’s short answer response suggests they think that scientific knowledge can change. They also assert that new interpretations, or more information can change ideas (discussion of Pluto). This is consistent with their responses for statements A, C, and D. The last sentence was interpreted to address statement B--old ideas can be replaced with new ideas. Their response does not specifically address what role new evidence plays in the replacement of old ideas, however, what is written suggests the student thinks that scientific knowledge (“ideas”) can be replaced, which is inconsistent with their Likert response to statement B, and therefore this response set was graded as “Not consistent.”

Well supported and established scientific knowledge does change over time. Science wouldn’t be evolving and changing if ideas couldn’t be argued and changed. For example, I grew up thinking Pluto was a planet. Now, scientists have discovered that it doesn’t meet all of the requirements to be called a “planet.” It has been lowered in status. As technology continues to improve, old ideas will be replaced with new ones.

Discovery and Invention:
These four statements are complex to evaluate. Student misconceptions about laws and theories can influence their responses. Also, among many scientists investigating this instrument, they struggled with the negative connotation of the word “invented”. In order to gage whether or not short answer responses were consistent or not, the evaluators looked to see if the students concluded whether or not theories were invented or discovered and whether or not laws were invented or discovered. In the original construction of the instrument, statements A and C were intended to be contradictory and statements B and D were intended to be contradictory. It appears that this category was confusing to the students, as only 2/3 of student responses were graded as “Consistent,” much lower to the other categories in which at least 90% of student responses were graded as “Consistent.”
In the first student example, the student articulates that they think that scientific laws and theories are discovered. From this, we would expect the pattern in their Likert statements to be 1,1,1,1. However, their Likert responses do not agree. The student strongly disagrees that theories are discovered and disagrees that theories are invented. They strongly agree that laws are discovered and agree that laws are invented. Their Likert responses contradict one another and disagree with their short answer response, so the response set was graded as “Not consistent.”

I believe scientific laws and theories are discovered because the golden ideas were in effect before the miner discovered them. The author gets credit for “writing” the laws that orchestrate the effect though. Einstein was given credit for the theory of
In the second student response set, the student articulates in their short answer response that they think that laws are discovered and theories are invented. From this, we would expect the pattern in the Likert responses to be 5,1,5,1, which is what we see. Though the student did not explicitly say “invented” when referring to theories, they alluded to the writing of a story, which references the prompt “assume...an author “invents” a story.” This statement was graded as “Consistent” because the pattern in the Likert responses matched what was written in the short answer response.

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>y</td>
<td></td>
</tr>
</tbody>
</table>

Scientific laws are discoveries of consistently recurring events in nature, discovered to be recognizable. Scientific theories are explanations of observed phenomena, attempting to weave a story that ends with the result we observe.
APPENDIX E: GEOLOGIC TIME LESSON PLAN AND HANDOUTS

Geology 100L
Geologic Time Lesson Plan

Goals:
Teach students about methods and evidence scientists have used to determine the age of the earth.
Familiarize students with the process of radiometric dating.
Teach students about the geologic history of Iowa.
Help students visualize the vast size of geologic time and the relatively small proportion of time life has existed on Earth.

Materials:
Pennies
Iowa Geology activity job descriptions and information
Iowa Geology activity samples
Chalk
Representative rocks for the time scale
Animal figurines for the time scale

Activities:

Part 1: Isotope Penny Activity
Have students form groups of two. Give each group twenty pennies. Pennies will represent the atoms of different isotopes in a mineral/crystal. Pennies that land heads up represent the parent isotope, and pennies that land tails up represent the daughter isotope. For this exercise, explain to the students that they will be representing the radioactive decay of the Uranium-Lead system. So, heads up pennies will represent $\text{U}^{238}$ and tails up pennies will represent $\text{Pb}^{206}$.
Each group of students should place all their pennies of the lab table heads up. Ask the students to count the number of pennies that are heads up (20 for each group). Create a table on the board with time in the x (left) column and number of parent isotope/heads up pennies in the y (right) column. Write a zero in the time column and the initial number of pennies in the y column. The table below gives an example for 10 groups of students.

<table>
<thead>
<tr>
<th>X (number of half-lives)</th>
<th>Y (number of U-238 atoms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>t=0</td>
<td>200</td>
</tr>
<tr>
<td>t=1 (4.5 billion years)</td>
<td>~100</td>
</tr>
<tr>
<td>t=2 (9 billion years)</td>
<td>~50</td>
</tr>
<tr>
<td>t=3 (13.5 billion years)</td>
<td>~25</td>
</tr>
</tbody>
</table>

Next, have each group of students pick up their pennies and shake them and toss them down on the lab table. Have the students count the number of heads up pennies and set aside the tails up pennies. Tally to total number of heads up pennies, writing the number in the y column and t= 1 (4.5 billion years) in the x column. Repeat this exercise, having students toss only the pennies that were heads up from the previous round. Each time, tally the number of heads up pennies in
the y column and mark the number of years in the x column. Stop this exercise when each group of students gets down to two or three pennies.

Next, convert the number of heads up pennies (parent isotope) into a percentage of total pennies and add this information to the table. Graph your data on the board (see example graph below).

<table>
<thead>
<tr>
<th>X (number of half-lives)</th>
<th>Y (number of U-238 atoms)</th>
<th>Percentage parent</th>
</tr>
</thead>
<tbody>
<tr>
<td>t=0</td>
<td>200</td>
<td>100%</td>
</tr>
<tr>
<td>t=1 (4.5 billion years)</td>
<td>~100</td>
<td>~50%</td>
</tr>
<tr>
<td>t=2 (9 billion years)</td>
<td>~50</td>
<td>~25%</td>
</tr>
<tr>
<td>t=3 (13.5 billion years)</td>
<td>~25</td>
<td>~12.5%</td>
</tr>
</tbody>
</table>

Lead the class in a discussion about the following questions:
What was the ratio of parent to daughter isotopes at the beginning?
How would the presence of daughter isotopes at the creation of the mineral affect the age of the sample?
How do scientists determine whether or not daughter isotopes were present at the creation of the mineral?
Do scientists choose any sample to do radiometric dating on?
Which types of rocks are most reliable for radiometric dating?

Students will complete the following questions for their lab assignment.
1. Complete the table for your class penny isotope illustration:
2. Draw the graph for the decay rate your class observed
3. How many years have passed if 75% of the atoms are U-238 atoms (heads up pennies) and 25% of the atoms are Pb-206 atoms (tails up pennies)?
4. How many years have passed if 67% of the atoms are U-238 and 33% of the atoms are Pb-206? (t\(_{age}\) = (half-life/0.693)*ln(1/y), where y = percentage of parent isotope remaining)
You will need to assist the students in making the calculation for question 4. You can walk through how to do the calculation with the class.

**Part 2: Iowa Geology Exercise**

For the next exercise, students will reconstruct two parts of the geologic history of Iowa. Break the students into groups of five and have them each pick a role (see Jobs list). If you have odd numbers of students, you can assign two people to serve as the paleoclimatologist or petrologist. Each student should get a unique set of information based upon the role. The students need to combine their information to reconstruct two different stages of geologic history in Iowa. The first stage represents a time when Iowa was a shallow marine sea and the second represents the recent glaciation. A key with all of the information is provided. Groups can start with either sequence of samples, but should analyze both. After looking at all of the samples, students should write a brief description of what Iowa was like during the two time periods and what evidence they used to come to that conclusion.

**Part 3: Construction of Geologic time scale to scale**

Once students have completed the Iowa geology activity, form them into two groups and have each group construct a representation of geologic history to scale. They should draw a straight line down the center of each lab bench. 1 mm = 1 million years.

Have students include the following points on their timescale:

- Each geologic age (dates provided on student handout)
- A piece of metaconglomerate, representing a sample from Western Australia, zircon dated at 4.4 billion years old.
- A piece of basalt, representing the oldest piece of oceanic crust, dated at 150-200 million years old (reference plate tectonics seafloor age map.)
- Each of the samples from the Iowa Geology exercise (they can mark them with chalk)
- Dinosaurs: 250-65 Ma
- Fish: 540 Ma
- Modern Horses: 1 Ma (ancestors were 50 Ma)
- First simple cells: 3.6 billion years ago
- Modern humans: 200,000 years ago

**Student assignment questions:**

How old do scientists think the age of the earth is?
What evidence do scientists use to support this age?
1. Complete the table for your class penny isotope illustration:

2. Draw the graph for the decay rate your class observed.

3. How many years have passed if 75% of the atoms are U-238 atoms (heads up pennies) and 25% of the atoms are Pb-206 atoms (tails up pennies)?

4. How many years have passed if 67% of the atoms are U-238 and 33% of the atoms are Pb-206? \( t_{age} = \left(\frac{\text{half-life}}{0.693}\right) \ln(1/y) \), where \( y \) = percentage of parent isotope remaining.

5. Write out a description of the two parts of Iowa’s history you explored when looking at the hand-samples. Use evidence to support your conclusions.

6. How old do scientists think the age of the earth is? What evidence do scientists use to support this age?
**Geochronologist:**
As a geochronologist, you use radiometric dating to determine the absolute ages of rocks. Radiometric dating compares the ratios of radioactive isotopes to their daughter atoms, or the atoms they decay into. Using the ratio of the parent and daughter isotopes and the known decay rate for the parent isotope, scientists can determine the age the mineral was formed. Scientists choose multiple mineral samples from the same rock to calculate the age, and only choose samples that show no signs of the possibility of daughter or parent isotopes escaping from the system. Radiometric dating works best on igneous rocks. Carbon-14 dating is a type of radiometric dating and can be used to calculate ages of organic material, but can only be used to date items that are up to 75,000 years old.

Your job in this activity is to communicate to your group the ages of the different samples. In some cases, you will be given the percentage of parent isotope remaining and will be asked to calculate the absolute age of the sample, in others you will be given ranges of dates for the life of a species which represents a relative age for the sample. You will have no information for some samples. You will also be responsible for writing down all of the information your groups come up with. Help out your other group members along the way too!

**Petrologist:**
As a petrologist, you determine the different minerals present in a rock and classify that rock. Many petrologists look at thin sections of the rock under a microscope to determine mineraologial composition, but you will be relying on the identification skills you developed earlier in the semester. Your job for this activity will be to determine the identity of each rock sample (not all samples are rocks). Communicate what you find to the group and help out your other group members along the way!

**Paleontologist:**
As a paleontologist, you classify and identify fossils. You use your knowledge of biology to distinguish between different species.

Your job for this activity is to identify the fossils present. Use your fossil classification guide to help you out! Communicate what you find to the group and help out your other group members along the way!

**Paleoclimatologist:**
As a paleoclimatologist, you use your knowledge of current environments to try and understand the environments of the past.
Your job for this activity is to try and determine the environment in which your group’s samples were formed or deposited. Use the information sheet and your group member’s knowledge to do this! Communicate what you find to the group and help out your other group members along the way!

**Stratigrapher:**
As a stratigrapher, you classify and identify the different layers of rock. For example, a stratigrapher would determine the boundaries between different layers and describe the different layers at the Grand Canyon.

Your have an important role in this activity. You will be provided with some information about the samples (pg 1), but your primary role is to draw a stratigraphic column on pg 2. You can look at the Iowa Stratigraphic Column provided as an example. The oldest rocks or units should be drawn at the BOTTOM of the column and the youngest rocks at the TOP. You might not be able to perfectly distinguish between the layers. Give it your best shot! The top of the column represents the layer that is closest to the surface. Along with drawing the column, be sure to add a description of what is in each layer. **ASK** lots of questions!

Example column

<table>
<thead>
<tr>
<th>Section D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandstone (youngest)</td>
</tr>
<tr>
<td>Shale (plant fossils)</td>
</tr>
<tr>
<td>Cross bedding</td>
</tr>
</tbody>
</table>
Geochronologist:

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-01</td>
<td>No date was available on this sample</td>
</tr>
<tr>
<td>B-02</td>
<td>Spirifers existed between 450-250 million years ago</td>
</tr>
<tr>
<td>B-03</td>
<td>Hexogonaria existed between 400-375 million years ago</td>
</tr>
<tr>
<td>B-04-A</td>
<td>No date was available on this sample</td>
</tr>
<tr>
<td>B-05-A</td>
<td>No date was available on this sample</td>
</tr>
<tr>
<td>B-06</td>
<td>Lepidodendron trees existed from 360-300 million years ago</td>
</tr>
<tr>
<td>B-07</td>
<td>No date was available on this sample</td>
</tr>
<tr>
<td>B-08</td>
<td>No date was available on this sample</td>
</tr>
<tr>
<td>C-01</td>
<td>73.3% of the original U-238 was found in a zircon in this sample.</td>
</tr>
<tr>
<td>C-02</td>
<td>Wood from this sample was analyzed and 16.3% of the original Carbon-14 remains.</td>
</tr>
<tr>
<td>C-03</td>
<td>This bone contains 54.6% of the original amount of Carbon-14</td>
</tr>
<tr>
<td>C-04</td>
<td>No date was available on this sample</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parent</th>
<th>Daughter</th>
<th>Half-life</th>
<th>Decay</th>
<th>Sample dated</th>
</tr>
</thead>
<tbody>
<tr>
<td>U 238</td>
<td>Pb 206</td>
<td>4.5 billion</td>
<td>8 alpha, 6 beta</td>
<td>Zircons</td>
</tr>
<tr>
<td>Rb 87</td>
<td>Sr 87</td>
<td>48.8 billion</td>
<td>Beta decay</td>
<td>Muscovite, biotite, K-spar, metamorphic or igneous rocks</td>
</tr>
<tr>
<td>K 40</td>
<td>Ar 40</td>
<td>1.3 billion</td>
<td>Electron capture</td>
<td>Glaucinite, muscovite, biotite, hornblende, volcanic rocks</td>
</tr>
<tr>
<td>C 14</td>
<td>N 14*</td>
<td>5730</td>
<td>Beta decay</td>
<td>Organic material</td>
</tr>
</tbody>
</table>

Petrologist:

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Minerals present</th>
<th>Other notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-01</td>
<td>Calcite</td>
<td>Fossils are present</td>
</tr>
<tr>
<td>B-02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B-03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B-04</td>
<td>Calcite</td>
<td>Small, spherical grains</td>
</tr>
<tr>
<td>B-05</td>
<td></td>
<td>Preserved Sedimentary structure</td>
</tr>
<tr>
<td>B-06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B-07</td>
<td></td>
<td>Composed of plant material</td>
</tr>
<tr>
<td>B-08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-02</td>
<td></td>
<td>Contains fine grained sediment as well as rocks</td>
</tr>
<tr>
<td>Sample #</td>
<td>Notes</td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>--------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>B-01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B-02</td>
<td>Same unit as B-01</td>
<td></td>
</tr>
<tr>
<td>B-03</td>
<td>Same unit as B-01</td>
<td></td>
</tr>
<tr>
<td>B-04</td>
<td>Occurs below B-05-A</td>
<td></td>
</tr>
<tr>
<td>B-05</td>
<td>Occurs at the top of the section</td>
<td></td>
</tr>
<tr>
<td>B-06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B-07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B-08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-01</td>
<td>Order given in story</td>
<td></td>
</tr>
<tr>
<td>C-02</td>
<td>Order given in story</td>
<td></td>
</tr>
<tr>
<td>C-03</td>
<td>Order given in story</td>
<td></td>
</tr>
<tr>
<td>C-04</td>
<td>Order given in story</td>
<td></td>
</tr>
</tbody>
</table>

Stratigrapher:

Glacier story:
One spring day in Ames, Farmer Joe was out plowing his fields. All of a sudden he turned up a bone (C-01)! This really got him interested! What kind of creature did the bone come from? How did it get there? Was there more? Farmer Joe was so intrigued that he decided to dig a hole in the field to figure out these questions. He dug a few feet down through the topsoil and found an odd material that was very much different than the topsoil (C-03). It was poorly sorted, meaning that it had very fine particles along with larger rocks. In this material he found a boulder as big as his refrigerator (C-02)! After getting the boulder out (which was quite the endeavor--he had to call in his neighbors Farmer Bob and Farmer Paul and it took both their trucks to pull it out!), he dug a while longer and came to the end of the odd material. Beneath that, he again discovered rock, but it was much more extensive than the boulder, stretching out in all directions, and covered in strange features that looked like scratch marks (C-04). Back aching, and convinced this was as far as he could get with his trusty shovel, Farmer Joe brought all his finds to Iowa State for interpretation. Farmer Joe wants to know what all of these samples are and why they are all in his field.