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Revisions of Physical Geology Laboratory Courses to Increase the Level of Inquiry: Implications for Teaching and Learning

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ABSTRACT

The introductory physical geology laboratory courses taught at North Carolina State University aims to promote scientific thinking and learning through the use of scientific inquiry–based activities. A rubric describing five possible levels of inquiry was applied to characterize the laboratory activities in the course. Two rock and mineral laboratory classes and a geologic time laboratory class were found to contain a greater proportion of low-level inquiry activities than the other laboratory classes. Student exercises within these classes were modified by increasing the degree of student independence, exploration, and prediction required for several activities. Such modifications included students categorizing rock samples before instruction on rock types and predicting the placement of fossils along a geologic time line. Learning gains were measured and compared between students in the traditional lower-inquiry (control) and the revised higher-inquiry laboratory classes (treatment). In all three classes, the increase in inquiry level was found to positively influence student academic performance on postlaboratory assessments and related exam questions. © *2015 National Association of Geoscience Teachers*. [DOI: 10.5408/14-050.1]

Key words: inquiry, rocks, minerals, geologic time

INTRODUCTION

Introductory geoscience laboratory courses often serve as a venue to reinforce concepts learned in the associated lecture and provide opportunities for students to gain hands-on experience with the nature of scientific inquiry. However, Singer et al. (2012) reported that "despite the importance of laboratories in undergraduate science and engineering education, their role in student learning has largely gone unexamined" (p. 137). Within the geosciences, some studies have shown that students enrolled in a laboratory class alongside a lecture course perform better in the lecture section of the course (Nelson et al., 2010) or on concept inventories (Forcino, 2013). Laboratory courses are important and need to be evaluated on their own merits to determine their effectiveness in promoting student learning.

Several agencies advocate that students gain science process skills (e.g., problem solving, data analysis, hypothesis testing) through inquiry-based learning (e.g., AAAS et al., 1991; NRC, 2000), which the National Research Council defines as:

> *a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations.*
>
> *(NRC, 1996, 23)*

The inclusion of these scientific inquiry components is especially important in introductory laboratory courses, which often represent the terminal science experiences for many non–science majors. Inquiry-based teaching methods have been demonstrated to significantly improve student learning and achievement in a range of science disciplines (Richardson and Renner, 1970; Mattheis and Nakayama, 1988; Geban et al., 1992; Basağa et al., 1994; Mao et al., 1998; Chang and Barufaldi, 1999; Apedoe et al., 2006; McNeal et al., 2008). Further, students who participated in inquiry laboratory courses described them as more engaging (Basey et al., 2008), were more likely to demonstrate scientific behaviors (observing, analyzing, predicting, etc.) and participate in discussions (Cianciolo et al., 2006; Xu and Talanquer, 2013), and showed greater improvements in science literacy and process skills (Brickman et al., 2009; Derting and Ebert-May, 2010; Treacy et al., 2011).

There is some limited evidence that students in geoscience laboratory courses featuring inquiry show similar gains. McNeal et al. (2008) demonstrated that students in an inquiry-based coastal eutrophication laboratory showed significant learning gains and performed better on laboratory assignments than students in a traditional workbook-style laboratory class. Miller et al. (2010) analyzed student understanding of sand-sediment transport in both a traditional and inquiry version of an introductory physical geology laboratory class. Students in the inquiry-based laboratory class showed greater improvements in critical thinking and communication skills, and in content and conceptual understanding (Miller et al., 2010).

This paper describes changes that were made to three introductory physical geology laboratory classes in order to increase the level of inquiry within each laboratory. The term "class" refers to a weekly physical geology laboratory that addressed a specific topic (e.g., geologic time). The physical geology lab course was composed of eleven separate classes and students enrolled in more than twenty sections of the course per semester. Consequently, each week, the same class was taught more than 20 times to different groups of

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TABLE I: Inquiry rubric (Buck et al., 2008).

Characteristic	Confirmation	Structured	Guided	Open	Authentic
Problem/question	Provided	Provided	Provided	Provided	Not provided
Theory/background	Provided	Provided	Provided	Provided	Not provided
Procedures/design	Provided	Provided	Provided	Not provided	Not provided
Results analysis	Provided	Provided	Not provided	Not provided	Not provided
Results communication	Provided	Not provided	Not provided	Not provided	Not provided
Conclusions	Provided	Not provided	Not provided	Not provided	Not provided

between 12-20 students. First, we describe the process by which changes were made to each laboratory class, as well as the impacts that the changes had on the inquiry level of the activities. Next, we describe how student academic performance was evaluated for students in original and revised sections of these laboratory courses to assess the impact modifications had on student learning. Finally, we discuss the implications of this work for instructors seeking to add or modify activities in their own introductory geoscience laboratory courses.

LABORATORY COURSE REVISION PROCESS

In the fall of 2009, we reformatted the activities in our physical geology laboratory course to take advantage of local geological resources and create inquiry activities (see NRC definition above). These laboratory classes featured a minimum of instructor lecturing and were based around a series of collaborative student exercises that were specifically created for the course or were borrowed completely or adapted from online sources such as those available at the Science Education Resource Center (SERC; http://serc.carleton.edu). As we developed the materials, we made no explicit effort to classify the student activities on the basis of levels of inquiry or specific pedagogical strategies (e.g., peer learning, active learning, problem-based learning), although it is likely that some or all of these strategies exist among the laboratory activities. Each of the 11 weekly laboratory classes taught in the physical geology course (MEA 110) lasted 2 h and 45 min, and students completed between three and seven activities per laboratory class.

We had been teaching the laboratory courses for several years before becoming aware of a paper by Buck et al. (2008) that contained a rubric for evaluating the inquiry level of laboratory activities. Buck et al.'s rubric removes much of the ambiguity found in previous inquiry classification schemes that were thwarted by inconsistent definitions and a lack of practical examples of inquiry activities. The rubric defines five levels of inquiry that range from confirmation to authentic inquiry (Table I). Each inquiry level is defined on the basis of the presence or absence of six characteristics common to scientific investigations (Table I). The inquiry level of an activity is determined by how many of the characteristics are generated by students in contrast to those that are provided by the laboratory manual or instructor.

Buck et al. (2008) used their inquiry rubric to analyze 386 experiments from 22 college laboratory manuals across seven disciplines. Each experiment represented a complete sequence of laboratory activities from a manual, and it was given an overall inquiry rating. Only 8% of experiments were rated at higher inquiry levels (guided, open). The geoscience manuals that Buck et al. (2008) evaluated were among the lowest in terms of inquiry levels. They evaluated 63 experiments from four geoscience laboratory manuals and rated them all as confirmation. While the inquiry analysis results of published geoscience laboratory manuals is discouraging, the inquiry rubric can serve as a useful tool for analyzing and modifying laboratory activities to increase the overall inquiry level.

The following examples illustrate how the rubric was applied to classify various activities within the laboratory courses we analyzed. Lower-level inquiry (confirmation, structured) activities provide students with the problem, background information, procedures to follow, and describe specific steps for their analysis (Buck et al., 2008). Confirmation activities are typical "cookbook" laboratory exercises that require students to follow a set of procedures to arrive at a known conclusion. For example, an example of a confirmation activity would be if a laboratory manual described streak testing and stated that the mineral pyrite had a brownish-black streak and then asked the student to carry out a streak test on pyrite. Structured inquiry activities also provide many of the procedural steps but do not provide the answer (Table I). For example, students may be asked to complete a map of magnetic anomalies adjacent to an oceanic ridge and then interpret whether the patterns produced support the concept of seafloor spreading (Jones and Jones, 2009). In contrast, high-level inquiry (guided, open) activities provide the problem and leave aspects of the methods, analysis, and conclusions for the students to devise (Table I; Buck et al., 2008). An example of a guided inquiry activity would require students to observe maps of the global distribution of active volcanoes, seafloor ages, earthquake locations, and topography to characterize different types of plate boundaries (Sawyer and Henning, 2005). Open inquiry activities ask students to design their own experiment or procedures (Buck et al., 2008). Asking students to use a physical model of an earthquake machine to design an experiment and test hypotheses on the recurrence intervals of earthquakes (Hall-Wallace, 1998) would be an example of open inquiry. Authentic inquiry occurs when students are involved in every step of the scientific process, from asking their own research question to drawing their own conclusions; no authentic inquiry activities were recognized by Buck et al. (2008), and none was included in MEA 110.

Even though we had never attempted any formal assessment of the level of inquiry in the laboratory courses, anecdotal reports and comments on course evaluations indicated that students found some laboratory activities less engaging than others. We sought to apply the rubric to each of the laboratory activities to measure contrasts between

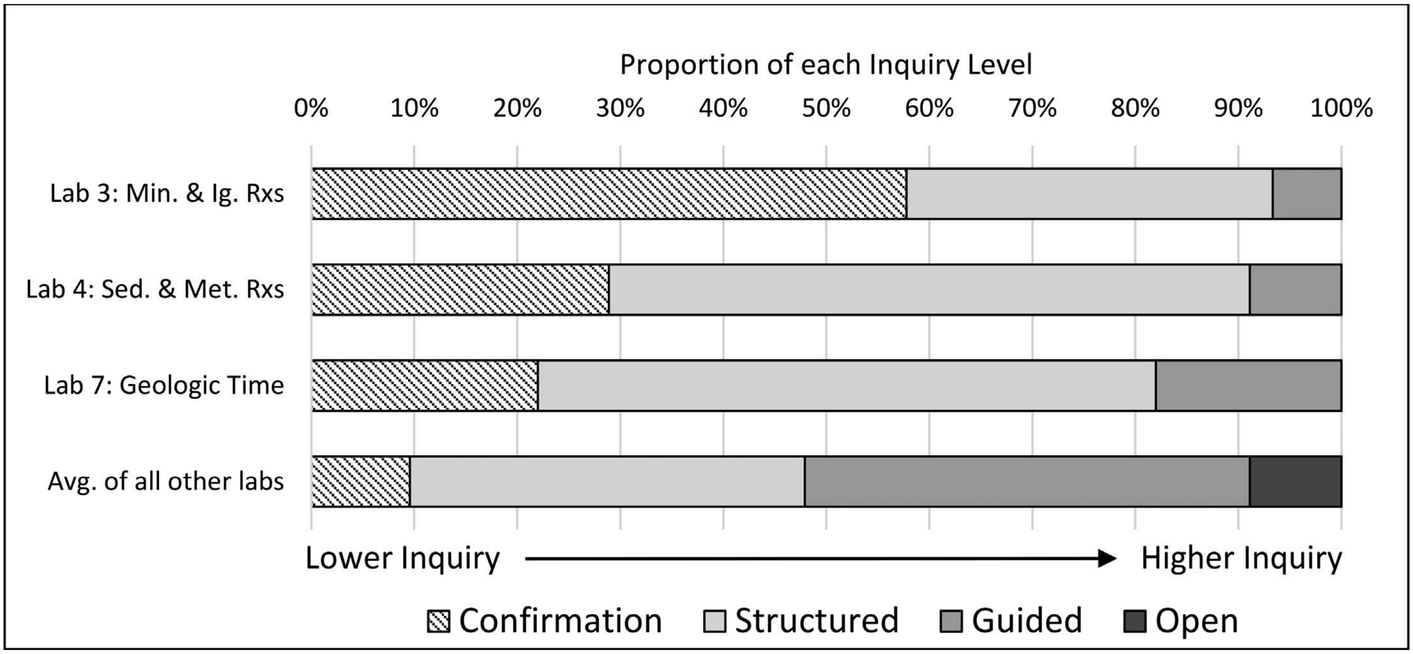


FIGURE 1: Proportion of inquiry levels found in original laboratory classes 3, 4, and 7 compared to the average for all other laboratory exercises. Laboratory classes 3, 4, and 7 are dominated by low-level inquiry activities.

activities and use these data to plan possible revisions. The 11 laboratory classes included a range of student inquiry activities and were divided into inquiry level percentages on the basis of the Buck et al. rubric (Fig. 1). The inquiry level of each laboratory activity was determined by analyzing how many of the inquiry characteristics were provided to the student versus how many were student driven. The point value of each activity was then divided by the total points available for the laboratory to arrive at an inquiry proportion. For example, a laboratory activity worth 50 points with a 20 point structured inquiry activity and a 30 point guided inquiry activity would be classified as 40% structured and 60% guided.

While most of the laboratory activities in the MEA 110 course were classified as being almost equally divided between lower- and higher-level inquiry, none of the activities in two rock and mineral laboratory courses and the geologic time laboratory course reached the level of open inquiry, and these laboratory course contained relatively few guided inquiry activities (Fig. 2). Consequently, we sought to

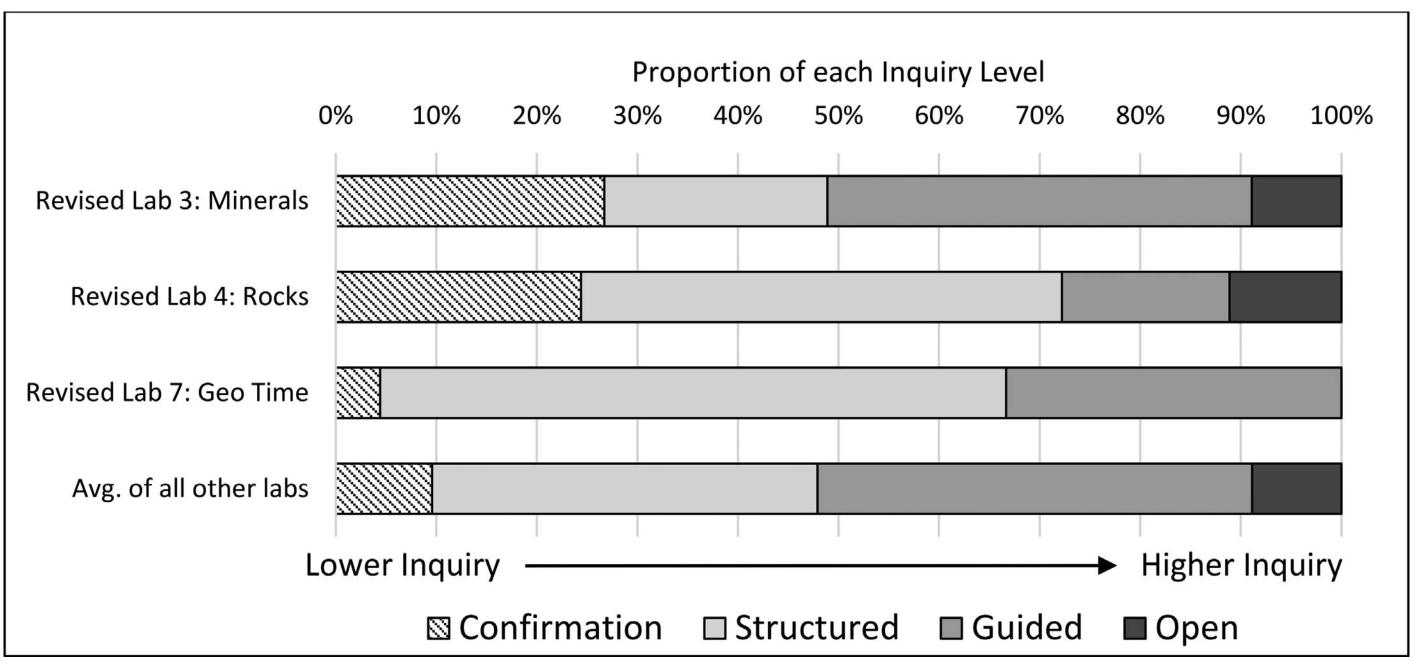


FIGURE 2: Proportion of inquiry levels found in revised laboratory classes 3, 4, and 7 compared to the average for all other laboratory exercises.

TABLE II: List of activities in the original and revised minerals (and igneous rocks) laboratory classes with associated point values and inquiry level.

Traditional Laboratory			Revised Laboratory		
Activity Name	Pts	Inquiry Level	Activity Name	Pts	Inquiry Level
Prelab part 1	4	Confirmation	Prelab part 1	2	Confirmation
Analysis of two igneous rocks	2	Guided	Prelab part 2	2	Open
Station 1: Hardness	3	Confirmation	Part 1: Intro to mineral ID	4	Guided
Station 2: Cleav. 1	3	Structured	Mineral ID table (1–3): Hard./col	2	Confirmation
Station 3/4: Cleav. 2	5	Confirmation	Mineral ID table (1–3): Cleav/luster	2	Structured
Mineral ID table: Col/ID	6	Confirmation	Mineral ID table (1–3): Name	1	Confirmation
Mineral ID table: Luster	3	Structured	Station 2/d: Cleavage/other	5	Confirmation
ID Minerals in Rocks: Pt. 1	2	Structured	Co-op learning mineral ID table	10	Guided
ID Minerals in Rocks: Pt. 2	1	Guided	ID Minerals in rocks: Pt. 1	2	Structured
Rock texture activity	3	Confirmation	ID Minerals in rocks: Pt. 2	1	Guided
ID igneous rocks: Texture	2	Structured	Part IV: Ore deposits	2	Confirmation
ID igneous rocks: V/P	2	Structured	Mining Q1	2	Guided
ID igneous rocks: Color	2	Confirmation	Mining Q2 and Q3	4	Structured
ID igneous rocks: Silica	2	Structured	Mining Q4	2	Guided
ID igneous rocks: Name	3	Confirmation	Mining Q5	2	Open
Igneous rocks and pressure-temperature setting	2	Structured	Part 6 & 7: Mineral uses and ID	2	Structured
Total:	45	Confirmation: 57.8%	**Total:**	45	Confirmation: 26.7%
		Structured: 35.5%			Structured: 22.2%
		Guided: 6.7%			Guided: 42.2%
		Open: 0%			Open: 8.9%

revise these three laboratory courses to increase the proportion of higher-level inquiry activities. The revision process for these laboratory courses is described next.

Rock and Mineral Laboratory Courses

The original version of laboratory class three (minerals and igneous rocks) focused on the identification of 15 minerals and 15 igneous rocks. Students initially examined different physical properties such as hardness, cleavage, and luster. They then tested several of these properties for each of the 15 minerals and used a flow chart to determine the identity of each mineral. The igneous rock part of the laboratory class was similar, with students identifying 15 igneous rocks based on texture and composition (Table II). The original laboratory exercise was predominately composed of activities at lower inquiry levels (Table II and Fig. 1) as students completed tasks such as identifying the color or hardness of minerals (confirmation) or identifying one or more minerals in a plutonic igneous rock sample (structured).

The revised inquiry-based laboratory assignments were designed with an emphasis on hands-on activities that involved students designing experimental procedures, analyzing and communicating results, and drawing conclusions. The revised laboratory also focused on mineral identification but incorporated a "jigsaw" cooperative learning activity intended to actively involve students in their learning (Constantopoulos, 1994). This strategy has been found to increase learning in college geology classes by giving students the chance to construct knowledge while attempting to articulate their thinking (Bykerk-Kauffman, 1995). Students were divided into teams of three to five and were each assigned a letter representing a fraction of the 15 minerals. For example, students assigned to the "A" group worked to individually identify the first five minerals. Students then moved into an expert group with all of the "A" students working together. This part of the exercise involved the assessment of individual interpretations among students who identified the same minerals. Once a consensus had been reached, students returned to their original groups and taught the other students about their minerals. While students in this revised exercise filled out the same table of 15 minerals as students in the traditional laboratory course, they spent more time analyzing results and drawing conclusions on their own. This activity was categorized as guided inquiry because students engaged in analysis and communication of their results, and conclusions were not provided (Table II).

The inquiry level of this laboratory exercise was further increased by having students conduct their own "cookie mining" exercise as a mining and reclamation simulation (modified from Wasserman and Scullard, 1994). This activity involved the use of food (chocolate chip cookies), which has been found to promote active learning and to serve as an analogy for students to better understand abstract concepts (Winstanley and Francek, 2004). During this activity, students worked in hypothetical mining company groups to design their own mining experiment. The groups chose

TABLE III: List of activities in the original and revised rocks laboratory classes with associated point values and inquiry level.

Traditional Laboratory			Revised Laboratory		
Activity Name	**Pts**	**Inquiry Level**	**Activity Name**	**Pts**	**Inquiry Level**
Prelab	4	Confirmation	Prelab	4	Confirmation
ID sed. char: Size	1.5	Confirmation	Intro key activity	5	Open
ID sed. char: Minerals	1.5	Structured	Ig ID table: Comp #	2	Guided
Sed. history	3	Confirmation	Ig ID table: Texture, V/P, col	6	Structured
Vials 7 & 8	2	Guided	Ig ID table: Color/name	2	Confirmation
Sed. to sed. rock	3	Structured	Igneous rocks and pressure-temperature setting	3	Structured
Crystal vs. clastic: Minerals	1.5	Structured	Intro sed. rocks: Compare	4	Guided
Crystal vs. clastic: Props	1.5	Confirmation	ID sed. char.: Size	1	Confirmation
Crystal vs. clastic: Chem	2	Structured	ID sed. char.: Minerals	1	Structured
Clastic vs. chem. vs. bio	2	Structured	Sed. history	1	Confirmation
Sed. rock ID chart	12	Structured	Vials 7 & 8/matching	3	Structured
Meta. temp window: a	1	Structured	Clastic vs. chem. vs. bio	3	Structured
Meta. temp window: b	1	Guided	Sed. ID chart: Comp. #	1.5	Guided
Meta. facies	1	Confirmation	Sed. ID chart: Name/char.	2.5	Structured
Meta ID chart: Fol&prop	6	Structured	Types of metamorphism	1	Confirmation
Meta ID chart: Name	2	Confirmation	Meta. ID chart: Comp #/ID	2	Confirmation
			Meta. ID chart: Fol./size	3	Structured
Total:	45	Confirmation: 28.8%	**Total:**	45	Confirmation: 24.4%
		Structured: 64.4%			Structured: 47.8%
		Guided: 6.7%			Guided: 16.7%
		Open: 0%			Open: 11.1%

between different land areas (cookie type) and mining tools (paperclips or toothpicks). The objective was to mine the most ore (chocolate chips) to make the most profit. This mining exercise was an example of a guided inquiry activity in which only the problem/question, theory/background, and procedures/design were given to the students. Results analysis, results communication, and conclusions were left up to the students to design. The revisions to laboratory class three reduced the amount of confirmation inquiry from 57.8% to 26.7% while increasing the amount of guided inquiry from 6.7% to 42.2%. The revisions also added 8.9% of open inquiry where there was zero before (Table II and Fig. 2). Due to time constraints, the revised version of laboratory class three no longer included igneous rock identification; these activities were moved to laboratory class four.

The original version of laboratory class four (sedimentary and metamorphic rocks) required that students examine one box of 15 sedimentary rocks and one box of 15 metamorphic rocks. Students completed activities that helped them learn how sedimentary and metamorphic rocks are classified before they identified the rock samples. These activities were repetitive and typically rated as low inquiry (Table III and Fig. 1).

One of the main revisions made to laboratory class four was that students learned about igneous, sedimentary, and metamorphic rock types in a single laboratory class. The first activity that students completed in revised laboratory class four was to work collaboratively in small groups to devise a systematic way of classifying 15 rock samples (a mixture of igneous, sedimentary, and metamorphic rocks). Students were not told which samples represented which rock type, and they were not given any information about how to categorize the rocks. They were asked to identify as many characteristics as possible to develop an identification key. Groups then traded keys and rock samples and applied the classification scheme of their peers to classify the rock samples. When finished, they communicated their results to the other group to determine if they had placed the samples in the correct category. This required analysis by both the groups who made and who applied the key. This activity was categorized as open inquiry because only the problem/question and theory/background were given to the students. After this activity, students were introduced to the ways in which the different rock types are classified. They then used this information to determine which of the 15 rocks were igneous, sedimentary, or metamorphic. Revisions to laboratory class four resulted in a decrease in structured inquiry activities (64.4% to 47.8%) and increased guided inquiry (6.7% to 16.7%) and open inquiry (0% to 11.1%; Table III and Figs. 1 and 2).

Geologic Time Laboratory Course

The geologic time laboratory class was divided into three components: Earth history, relative dating, and absolute dating, with the original Earth history portion of the laboratory taught almost entirely at the confirmation level of inquiry. This portion of the laboratory class was taught largely using one central analogic activity. Students began by reading about the geologic time scale and then placed

TABLE IV: List of activities in the original and revised geologic time laboratory course with associated point values and inquiry level.

Traditional Laboratory			Revised Laboratory		
Activity Name	**Pts**	**Inquiry Level**	**Activity Name**	**Pts**	**Inquiry Level**
Prelab	4	Structured	Prelab Q1 & Q4	2	Structured
Time scale math	1	Structured	Prelab Q2	1	Confirmation
Time line participate	5	Confirmation	Prelab Q3	1	Guided
Article Q1	2	Structured	Time line eqs. & predict	5	Structured
Article Q2 & Q3	4	Confirmation	Time line Q4–Q6	6	Guided
Relative dating	8	Structured	Timescale demarcate Q	1	Structured
Creating cross section	6	Guided	Relative dating	8	Structured
Half-life demo	1	Confirmation	Creating cross section	6	Guided
Half-life Q's	12	Structured	Half-life demo	1	Confirmation
Ages of NC rocks	2	Guided	Half-life Q's	12	Structured
			Ages of NC rocks	2	Guided
Total:	45	Confirmation: 22.2%	**Total:**	45	Confirmation: 4.5%
		Structured: 60%			Structured: 62.2%
		Guided: 17.8%			Guided: 33.3%
		Open: 0%			Open: 0%

geologic events along a 46 ft (14 m) tape measure to represent Earth's 4.6 billion year history. During the activity, each student was given a piece of paper with an event and its age in millions of years ago. The student then converted the age of their event to a scale of feet and inches and physically placed the paper at the appropriate location along the 46 ft (14 m) tape measure. Students also completed a smaller football field analogy activity where they calculated the yard line distance of the end-Permian extinction. Because the laboratory manual listed all of the geologic time periods and major events that students placed on the 46 ft (14 m) time line, these activities were classified at the confirmation level.

The principal revisions made to this laboratory class included omitting student readings, upgrading the time-line activity, and rewriting the prelaboratory activity (Table IV). The time-line activity was modified so that students were given either a picture (such as a paleomap) or a fossil and were asked to predict the timing of their event (e.g., first appearance for fossils) by placing it along the tape measure. Working as a class with no prior instruction, students constructed an initial scaled time line that represented 20 key events of Earth's history based on their predictions. Students were encouraged to work together and discuss their time-line predictions to refine their timings and the relative placement of events. After the students were satisfied with their time line, each student was provided with the correct geologic age of their event. Students then calculated the correct placement of their event and moved their item to the appropriate location along the tape measure to create an accurate time line. The addition of the prediction component not only raised the inquiry level of the activity, but it potentially makes the time-line analogy a more effective exercise for students because making predictions before demonstrations can enhance student learning (Crouch et al., 2004). Finally, students worked together to identify two boundaries on the time line and justify their selection; i.e., identify what is different on each side of their boundaries. New questions were also written to facilitate student-driven analysis and communication of the results from the time-line activity. Questions prompted students to analyze the fossil distribution along their tape measure and draw conclusions about their observations based on comparison to the actual geologic time scale.

Analysis of the original laboratory exercise revealed that most of the activities were classified as low-level inquiry (Table IV and Fig. 1). The revisions reduced the amount of confirmation in the geologic time laboratory class from 22% to 4.5% while increasing guided inquiry from 18% to 33% (Figs. 1 and 2). This shift from confirmation to guided inquiry occurred solely in the Earth history portion of the laboratory exercise, as the relative and absolute dating portions of the laboratory course remained unchanged.

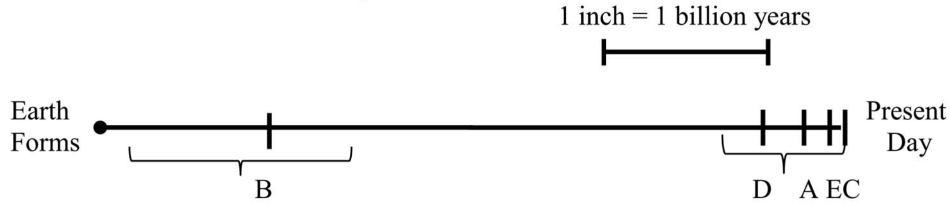
ASSESSMENT METHODS

The assessment of student academic performance due to revisions of the rock and mineral laboratory classes occurred in fall 2013 (Grissom, 2014) and in the geologic time laboratory class during spring and fall 2013 (Czajka, 2014). For the rock and mineral laboratory classes, 207 students were enrolled in revised laboratory sections, and 153 were enrolled in the traditional laboratory sections. The geologic time laboratory includes data from the spring and fall 2013 semesters, with 272 students enrolled in the traditional laboratory class, while 252 were in the revised laboratory group. The revised laboratory sections will be considered the treatment group in this study, and the traditional laboratory sections are the control group.

Graduate teaching assistants taught all sections of the laboratory courses, with an average enrollment of 17 students per section and a maximum of 20. The majority of students enrolled in the fall 2013 semester were freshman (58.1%) and sophomores (23.7%). Most (79.1%) were non–science, technology, engineering, and mathematics (STEM) majors, 16.7% were STEM majors, and 4.2% were undecided

Using the timeline of Earth's history below, place a tick mark on the line to represent where each of the following events occurs. Label your tick marks with the appropriate letter. (9 pts)

A – Dinosaurs Appear
B – Origin of Life on Earth
C – Humans (Homo sapiens) Appear
D – First Organisms with Hard Parts (shells, skeletons, etc.) Appear
E – Non-Avian Dinosaurs go Extinct



Grading Rubric:

Tick marks are the precise locations of correct answers. Brackets show the range of acceptable answers.

3 Points if ALL letters are in the correct order = B-D-A-E-C.
4 Points if A, C, D, & E are within the last ¾" (1 pt. for each)
2 Points if B is within the first 1.5", but not at Earth's formation

FIGURE 3: Laboratory course final exam question on Earth history. Grading criteria are underlined.

or their major was not specified through the university. (No demographic data were obtained during the spring 2013 semester.)

Teaching assistants were randomly assigned to teach either a traditional or revised version of laboratory classes three (minerals), four (rocks), and seven (geologic time) using a random number generator in Microsoft Excel. All sections with a random number ending in an even number were assigned the revised laboratory courses; sections that ended in an odd number were assigned the traditional laboratory courses. Graduate teaching assistants were assigned to teach only one version of the laboratory course, and those who were assigned to teach the revised versions of the laboratory course were familiarized with the changes during weekly meetings.

Student performance was evaluated using data from multiple sources: (1) a pretest of conceptual knowledge; (2) assessment exercises following each laboratory exercise (postlab assessments); and (3) questions embedded in the midterm and final exams. All laboratory course students were given a 15 question pretest at the beginning of laboratory class three to test for prior content knowledge. The pretest consisted of questions taken from the Geoscience Concept Inventory (GCI) database (https://www.msu.edu/~libarkin/research_gci.html), ConcepTest questions from the Science Education Resource Center at Carlton College (SERC; http://serc.carleton.edu/introgeo/conceptests/), and the researchers' questions specific to the rock and mineral and geologic time laboratory classes. Only content related to the rock and mineral and geologic time laboratory classes was covered in this assessment. This pretest was used to assess whether there were any differences in student prior knowledge between the control and treatment groups.

Students completed a graded postlaboratory exercise assessment at the end of every laboratory class. These post–laboratory exercise assessments were analyzed to determine if students in the treatment group were learning more in the revised laboratory courses. The primary authors collected and graded the postclass assessments from every section for all laboratory exercises to ensure consistent grading (A.N.G. for rocks and minerals; C.D.C. for geologic time).

Students enrolled in MEA 110 also completed a midterm and final exam, worth 100 and 200 points, respectively. All exam questions relating to rock, mineral, and geologic time content were graded and analyzed by the primary researchers. Students answered a combination of multiple-choice, fill-in-the-blank, and short-answer questions. Most of the short-answer questions required students to identify rock and mineral hand samples. In order to better assess the efficacy of the laboratory course changes on student understanding of geologic time, a new assessment question was created for the final exam. The new question (Fig. 3) provided students with a 4.6 in. (11.7 cm) line to represent Earth's 4.6 billion year history. Students were asked to plot labeled tick marks on the line to represent the origin of life, first organisms with hard parts, dinosaur appearance, nonavian dinosaur extinction, and the appearance of humans.

ASSESSMENT RESULTS

Rock and Mineral Laboratory Class Results

The rock and mineral portion of the pretest was scored out of seven points for 200 students in the revised sections

TABLE V: Pretest results for rock and mineral and geologic time laboratory courses.

Lab Titles	Format	*n*	Mean	%	σ	Significance (Two-tailed)
Minerals and rocks	Original Lab	151	3.42[1]	48.9	1.49	$p = 0.357$
	Revised Lab	200	3.28[1]	46.9	1.47	
Geologic time spring 2013	Original Lab	71	3.10[1]	44.3	1.49	$p = 0.219$
	Revised Lab	93	3.39[1]	48.4	1.47	
Geologic time fall 2013	Original Lab	185	3.78[2]	47.3	1.35	$p = 0.720$
	Revised Lab	152	3.83[2]	47.9	1.21	

[1]Out of 7 points.
[2]Out of 8 points.

and 151 students in the traditional sections. The average score for students in all traditional sections was slightly higher than the average for the revised course students (Table V), but an independent *t*-test indicated that there was no statistically significant difference between these averages.

Student learning of material from these laboratory courses was measured using four assessments: (1) post–laboratory class three mineral color question; (2) post–laboratory class four Venn diagram; (3) post–laboratory class five rock and mineral identification; (4) midterm exam questions.

1. Post–laboratory class three assessment: An open-ended question asked students why we should be careful when using color to identify minerals and required them to give an example of why this is the case. Independent *t*-test results of mean scores indicated that the revised laboratory course students scored significantly higher on this question than the traditional laboratory course students (Table VI).
2. Post–laboratory class four assessment: The assessment activity asked students to place 12 rock properties on a triple Venn diagram with each circle representing a different rock type. Students sorted a series of statements about rock properties that were either exclusive to one rock type (e.g., "Forms from the cooling of magma") or were applicable to multiple rock types (e.g., "Classification is partially dependent on texture"). Students were awarded 1 point for each item that was placed in the correct area on the diagram for a total of 12 possible points. Independent *t*-test results of mean scores indicated that the revised laboratory course students scored significantly higher on this assessment than the traditional laboratory course students (Table VI).
3. Post–laboratory class five assessment: The final postlaboratory assessment used in this study came from the subsequent week's laboratory exercise (campus walking tour) and was the same for all laboratory sections. This assessment presented students with a box of 12 rock and mineral samples. Students were informed that the box contained three samples each of minerals, igneous, sedimentary, and metamorphic rocks. They completed three required questions and one optional extra credit question (see discussion and supplemental material; this can be found online at http://dx.doi.org/10.5408/14-050s1). Students in the revised sections scored significantly higher on both the first question and on the extra credit question, but there was no statistically significant difference on the second and third questions (Table VI).

TABLE VI: Student learning gains.

	Traditional			Revised			
	n	Mean	σ	*n*	Mean	σ	Significance[1]
Post–Lab 3 assessment: Why is color not a good method of classifying minerals?							
Q1 (2 pts)	153	1.34	0.76	193	1.52	0.66	$p = 0.019$
Post–Lab 4 assessment: Rock properties Venn diagram.							
Q1 (12 pts)	108	6.86	1.87	183	8.11	1.85	$p < 0.001$
Post–Lab 5 assessment: Rock and mineral identification.							
Q1 (3 pts)	137	1.43	1.09	180	1.7	0.96	$p = 0.02$
Q2 (2 pts)	141	1.5	0.5	181	1.55	0.59	$p = 0.459$
Q3 (2 pts)	141	1.74	0.67	163	1.72	0.7	$p = 0.733$
Q4 (2 pts)	101	0.84	0.57	138	1.29	0.68	$p < 0.001$
Midterm exam questions.							
(51 pts)	145	37.68	6.28	199	39.18	5.79	$p = 0.024$
Final exam Earth history question.							
Q1 (9 pts)	272	5.76	1.70	252	6.47	1.53	$p < 0.001$

[1]Two-tailed.

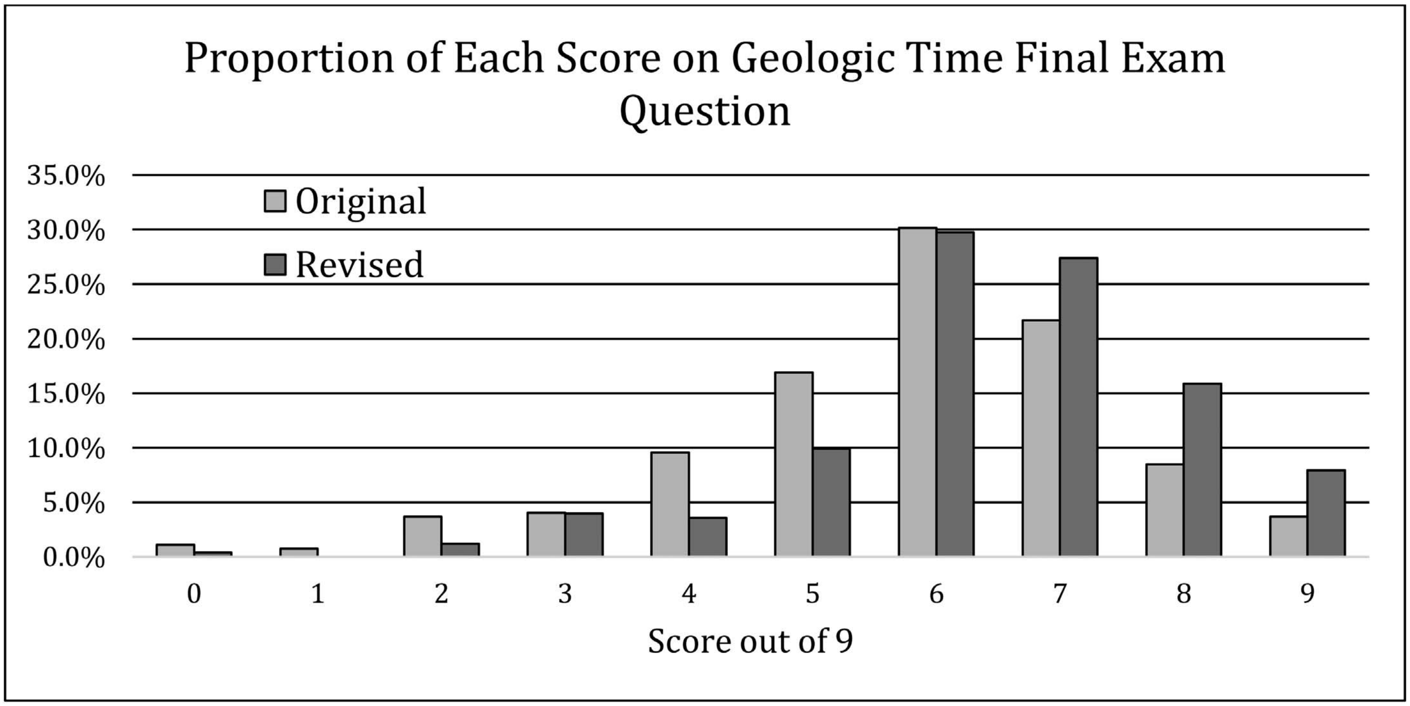


FIGURE 4: Student scores on laboratory course final exam Earth history question for traditional and revised laboratory sections.

4. Midterm assessment: An independent *t*-test of total mean scores out of the 51 possible points related to rocks and minerals indicated that the revised laboratory course students scored significantly higher on the rock and mineral portion of the exam than the students in the traditional laboratory course (Table VI).

Geologic Time Lab Results

Independent *t*-tests of mean scores on the pretest showed no statistically significant difference in prior knowledge between the students in the traditional laboratory course compared to those in the revised laboratory course sections (Table V). However, independent *t*-tests of mean scores for the Earth history question (Fig. 3) on the final exam showed that students in the revised laboratory courses scored significantly higher than those in the original laboratory course (Table VI). Figure 4 illustrates the proportion of students in the revised versus the original sections earning each score from 0 to 9 on the question.

DISCUSSION

Rock and Mineral Laboratory Classes

A significant outcome of the revisions made to the rock and mineral laboratory class was a reduction in the number of samples that students analyzed. Although they identified fewer samples, students in the revised laboratory courses still outperformed those in the traditional laboratory courses on almost all rock and mineral–related assessments (Table VI). For example, students in the traditional laboratory class four observed 30 more rock samples and spent about 45 min more on rock identification activities than the revised laboratory class students. In the revised guided inquiry laboratory class, students were not told which rock type their 15 samples represented, only that six were igneous, four were sedimentary, and five were metamorphic. The traditional confirmation inquiry laboratory students were told which rock type they were being asked to identify, and they were asked to identify features of the 15 rock samples. The revised laboratory course students spent more time analyzing the differences between the three rock types in order to group them, which likely contributed to their increased performance on the postexercise assessment.

Results of the postlaboratory exercise assessment from laboratory class five showed that students in the revised laboratory section scored significantly better when asked to identify three mineral samples in a box of 12 rock and mineral samples (supplemental materials, postlaboratory assessment questions; this can be found online at http://dx.doi.org/10.5408/14-050s1). Students in the revised laboratory class were spending the same amount of time on mineral identification as traditional laboratory class students, only with fewer samples and more focus on mineral identification process skills during the cooperative learning activity. Students in the revised laboratory class also did significantly better when asked to identify another sample in each category from the remaining eight specimens (Question 4). The more obvious samples had already been identified in Question 2, so students were left with samples that tested their identification abilities. In addition to performing better on this question, students in the revised laboratory class were also more likely (76.2% compared with 71.6%) to attempt the extra credit question, which asked them to further identify one additional mineral, igneous, sedimentary, and metamorphic rock. Finally, revised laboratory class students performed significantly better on the rock and mineral content portion of the midterm exam, even though they only had opportunity to identify half the number of rock and mineral samples as seen by traditional laboratory class students (30 versus 60 samples). These results may be interpreted to suggest that increasing time on task while reducing the number of samples may encourage more effective student learning (see also: Sundberg et al., 1994; Hoskins and Stevens, 2009; Luckie et al., 2012).

Geologic Time Laboratory Class

The revised higher-inquiry version of the geologic time laboratory class was effective at improving student conceptions of Earth history, as evidenced by scores on the final exam question. The analysis of student responses to this question revealed that some misconceptions persisted among students, even after inquiry revisions were made to the laboratory class. One of the most persistent misconceptions students seem to retain is in regards to the origin of life on Earth. Students commonly placed the origin of life much later than the known evidence for life on Earth around 3.5 billion years ago, thus underrepresenting the amount of time that microbial life flourished in the absence of animal life. The other prevalent misconception was that the origin of hard parts occurred too early. While the revised laboratory class emphasized that organisms with high preservation potential are a recent phenomenon over geologic time, it is possible that students were not distinguishing the nature of living microbes from microbial fossils preserved as rock that they encountered in the laboratory course. Adding a fossilization component to future revisions of the laboratory course may help address this issue.

Process of Change

Beyond simply adopting the laboratory activities described in this paper, it is hoped that instructors can utilize a similar process to assess and revise the inquiry level of their laboratory courses. The first step of this process is to assess the inquiry levels of each laboratory class using the rubric of Buck et al. (2008). Each individual activity can be assessed based on how many of the six inquiry characteristics are provided versus student driven (Table I). The advantage to breaking the inquiry down for each activity is that focused changes can be piloted for specific sections of laboratory courses without making wholesale changes to the complete laboratory class. After determining the inquiry breakdown of each laboratory exercise, a few with the highest percentage of lower-inquiry activities can be targeted for revision. The inquiry level of these activities can then be revised by thinking about ways for students to be more active in higher-level inquiry characteristics. The most straightforward changes are those that need relatively few additional resources and do not require additional time for completion. A few examples:

- Replace multiple fill-in-the-blank activities with fewer short-answer questions. For example, rather than asking students to identify the hardness of a set of minerals, consider asking them to identify three minerals within the sample set with a specific range of hardnesses. (Confirmation → structured inquiry.)
- Instead of having students follow instructions about how to classify a set of objects; ask them to first attempt to categorize the features themselves. We used this process in the rock classification exercise, but it could also be applied to a laboratory exercise seeking to classify minerals, fossils, or faults (using a combination of pictures, models, and specimens). Direct instruction on concepts (which have been identified by students) can then be reduced and appropriate vocabulary introduced as needed. (Structured → guided inquiry.)
- Exchange directions about how to do something with challenges to achieve a goal. For example, in early versions of our streams laboratory course, we gave detailed directions about how to measure discharge in a small stream on campus. We subsequently revised this assignment to have students design a way to measure discharge when presented with a small collection of measuring instruments. (This also works for calculating density.) (Structured → open inquiry.)

It is important to note that all of the introductory geology laboratory classes contain some lower-level inquiry activities and that these activities can still be effective for introducing basic information and may be more appropriate depending on the amount of class time, concepts to be learned, and ability level of the students. Instructors should always strive to scaffold their assignments with a mixture of both high- and low-level inquiry activities in order to maximize student learning.

Finally, after the laboratory classes had been in place for a couple of years, we examined how they were being taught by the graduate teaching assistants. Each teaching assistant experienced an initial training seminar led by the laboratory supervisor prior to the semester and subsequently participated in weekly training sessions focused on upcoming laboratory classes. While there was a small difference in the teaching practices of more experienced and novice teaching assistants, the greatest control on teaching practice was the inquiry level of the activities in the laboratory course itself (Ryker and McConnell, 2014).

Research demonstrates that inquiry-based instruction has positive impacts on student learning and performance (Rissing and Cogan, 2009; Derting and Ebert-May, 2010; among others), and our study of student academic performance and inquiry supports this idea. However, many of the studies on inquiry in laboratory courses have looked at replacing the traditional low-level inquiry laboratory course with a more authentic research-based laboratory course (Brownell and Kloser, 2011; Treacy et al., 2011; Luckie et al., 2012). While these types of changes are beneficial, they require a complete overhaul of the laboratory course, which involves considerable time, training, and resources (Brownell and Kloser, 2011). The approach presented here demonstrates how a rubric (Buck et al., 2008) can be used to evaluate the inquiry of existing laboratory activities and make targeted changes to improve the overall inquiry of a laboratory course. The laboratory classes we revised (rocks, minerals, and geologic time) are topics common to many introductory geology courses and may provide models for instructors seeking to make practical changes to geoscience laboratory courses.

CONCLUSIONS

We have described revisions made to three introductory physical geology laboratory classes that deal with rocks, minerals, and geologic time. These laboratory classes were chosen for revision because they represented the classes with the lowest levels of scientific inquiry as assessed using the rubric created by Buck et al. (2008). Not only did the revisions to these laboratory classes increase the inquiry level, but the academic performance of students in the revised laboratory courses was higher than those in the traditional version. The activities and assessments presented here can be readily implemented by other instructors interested in changing the way they teach these concepts in laboratory. (The most recent versions of each laboratory exercise are available here: https://sites.google.com/site/geosciencelearning/research/ncsu_mea110_labs.) The resource needs of these laboratory courses are reasonable, and the revised versions of the rock and mineral laboratory exercises may even reduce the number of hand samples required. Additionally, while it is engaging for students to use fossils during the geologic time activity, pictures of extinct organisms could be used if fossil samples are not readily available.

One concern that instructors may express in regards to implementing higher-inquiry activities is that such activities require class time that could be spent teaching more content that the students need to know. However, results of this study indicate that student academic performance increases when the focus is on higher-order inquiry skills rather than the volume of content. This suggests that quality is more important than the quantity of content and that the extra effort and time involved in both teaching and preparing high-level inquiry activities provide a benefit to students.

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