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Effective geoscience pedagogy at the undergraduate level

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Is approved by the final examining committee:

Dan Shepardson

Terry West

James McClure

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Head of the Department Graduate Program Date

EFFECTIVE GEOSCIENCE PEDAGOGY AT THE UNDERGRADUATE LEVEL

A Thesis

Submitted to the Faculty

of

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by

Kelsey Warden

In Partial Fulfillment of the

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To my mistakes- thank you for growth.

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TABLE OF CONTENTS

Page

Page

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

Active Learning: a practice of acquiring knowledge in an engaging manner involving activities, student participation, and student “presence”

Objectivist Pedagogy: A way of teaching that places complete academic control within the expert or teacher and treats knowledge as something to be given to the student by this person via communication

Constructivist Pedagogy: A way of teaching that place the expert or teacher in a role or facilitator rather that controller and treats knowledge as a part of the world that can only be acquired through experiences which allow the student to give meaning to new information as a means to link it to previously learned information

Science Literacy: A concept that promotes lifelong learning, appreciation, and understanding of science and its impact of the self and society

Think, Pair, Share: A learning practice that asks students to think about a question or concept posed to them, pair with another student to discuss what they thought about, and share their collaborative thoughts with the rest of the class

ABSTRACT

Warden, Kelsey T. M.S., Purdue University, August 2014. Effective Geoscience Pedagogy at the Undergraduate Level. Major Professor: Terry West.

This investigation used constructivist pedagogical methods within the framework of an introductory level undergraduate geoscience course to gauge both the changes in attitude and cognition of students. Pedagogy was modified in the laboratory setting, but maintained in the lecture setting and homework. Curriculum was also maintained in the lecture, but was changed in the laboratory to emphasize the large concepts and systems stressed in Earth Science Literacy Principles. Student understanding of these concepts and systems was strengthened by factual knowledge, but recall and memorization were not the goal of the laboratory instruction. The overall goal of the study was to build student understanding more effectively than in previous semesters such that the students would become Earth Science literate adults.

We hypothesized that a healthy comprehension of the connections between the human population and Earth's systems would lead to improved cognition and attitude toward Earth Science. This was tested using pre- and post-testing of attitudes via an anonymous survey on the first and last days of the laboratory, student responses to the end-of-course evaluations, and student performance on early-semester and late-semester content testing. The results support the hypotheses.

CHAPTER 1. INTRODUCTION

1.1 Introduction

We live on Earth. This statement is true to some degree, but the more appropriate assessment of our situation is that we live *with* the Earth. We coexist with her processes, species, and place in the universe. Of all the abstract ideas present in geoscience, the most difficult to grasp may be our simultaneous lack of control and undeniable ability to alter the state of the Earth. As teachers and scientists, it is our responsibility to help society actively participate in transforming this coexistence into a mutually symbiotic relationship. In many ways, this goal is already being worked towards with the development of the Earth Science Literacy Principles (ESLPs) in 2010 and the ongoing infusion of these principles into textbooks, pamphlets, and other media (Wysession et al., 2012). The ESLPs consist of nine structured "big ideas", the understanding of which defines Earth Science literacy.

We used the ESLPs and constructivist pedagogy to redesign an introductory geology laboratory. We applied two guiding principles to structure the content and character of the laboratory:

1) Most people learn best by doing.

2) We are educating citizens whose decisions impact our society, government, and environment

We wanted to create an environment in the laboratory that encouraged students to connect to the content in a personal and social way. We blended various effective teaching strategies from the literature (at the secondary and undergraduate level) to forge an effective method for conveying the bigger picture of geoscience while teaching the required geology content of the course. The course, Earth Through Time (EAPS 112), was an introductory geology course for non-geology majors, meeting for a one-hour lecture two times per week and for a two-hour and fifty minute lab once per week for fifteen weeks. There were two laboratory sections, with twenty-two students in the first section and twelve students in the second section.

1.2 Motivation

Earth Through Time is a popular course taught at the introductory undergraduate level. The course focuses on concepts fundamental to building an understanding of the Earth's development such as plate tectonics, the rock cycle, and the geologic time scale. The laboratory portion of the course requires the students to meet for a two hour and fifty minute period one day per week, fifteen times during the semester. In previous years, the laboratory was taught in the traditional lecture format, consisting of an introductory lecture followed by answering questions in a handout. Often, the distributed packets assessed little more than the students' abilities to look up terms or lists in their textbook. Exams tested the memorization abilities of the students (examples shown in Table 1.1). The literature suggests that these pedagogical practices and assessments are not effective and should be exchanged with methods that require students to critically think about their responses and explore ideas with care (see Chapter 2).

Table 1.1

Example Questions on Laboratory Exams and Packets

Exam Questions	Packet Questions
Name all of the types of plate boundaries (with their Sub-categories) and describe each boundary's association with earthquakes and volcanoes.	What are the three epochs of the Paleogene period? Give the times when each of these epochs started and ended. (Cenozoic Lab)
Define the term "multiple working hypotheses". Additionally describe the term's origin. Finally, recall and list 3 of the 4 hypotheses that were generated for the Kentland Quarry Impact Site.	Discuss the Middle Run Formation. What is its age and lateral extent? (Paleozoic Lab)
Examine the following 3 pages containing pictures of 27 fossils from the Paleozoic Era. Choose 20 of these and provide the proper name for each of them.	What are the 3 different particles given off by the radioactive decay of isotopes? What happens to each isotope in the process? Explain for each. (Dating Lab)

Previous studies have produced results suggesting that assessment and pedagogical styles be mirrored in such a course (Apedoe, 2006). To perform a complete reformation toward active learning and scientific literacy, exams, lectures, and activities were all restructured, and in some cases, replaced. Table 1.2 lists the laboratory dates and the topic covered, fieldtrip taken, or exam taken on that date.

Table 1.2

Topic of Each Laboratory Meeting

Date	**Topic/Exam/Fieldtrip**
8/23/2013	Introduction and the Scientific Method
8/30/2013	Igneous Rocks
9/6/2013	Metamorphic and Sedimentary Rocks
9/13/2013	Plate Tectonics
9/20/2013	Exam 1
9/27/2013	Absolute and Relative Dating
10/4/2013	The Origin of Life
10/11/2013	The Origin of Time: Precambrian
10/18/2013	The Paleozoic
10/25/2013	The Mesozoic: Triassic and Jurassic
11/1/2013	The Mesozoic: Cretaceous
11/8/2013	The Cenozoic
11/15/2013	Field Trip to Delphi Quarry
11/22/2013	Exam 2
12/6/2013	The Holocene and Anthropocene

1.3 Laboratory Modifications

Previous work has suggested that even at the undergraduate level, many students are not formal learners capable of understanding abstract ideas easily, and very few thrive in a passive learning environment (Leonard, 1997). In response, studies pertaining to the integration of active learning methods such as inquiry based learning have shown successes in increasing student content knowledge and scientific literacy (Apedoe, 2006; Brickman, 2009). Despite these successes, wide-ranging implementation is still an educational fantasy, possibly due to a resistance toward student-centered classrooms in courses with large enrollments. Assessment styles and classifications of student-centered pedagogy are also in early stages of solidification (Towns, 2008). Because laboratory sessions contain far fewer students than lecture, we used this time during the Fall 2013 semester to promote discussion and student-centered learning in two introductory geology laboratory sessions.

We restructured the laboratory component by implementing a constructivist methodology in place of the previous lecture and packet format. A renovated lesson plan was developed for each laboratory with at least one group activity per session. Use of the Internet for research purposes during these activities was encouraged. Active learning strategies such as group learning, project based learning, and inquiry based learning formed the basis for student participation. Communication in the form of group presentations was a staple of each laboratory, and an open discussion format was maintained. To support English Language Learners, literacy-oriented visuals and handouts were distributed at the beginning of each session. These lesson plans encouraged students to problem solve, communicate effectively, work in teams, and explore data.

A consistent schedule was adapted to increase the predictability of how class time would be spent. No more than the first twenty minutes were spent reviewing information using PowerPoint. The slides were designed in accordance with previous studies on the effectiveness of slide format and use in class (Susskind, 2006; Apperson, Laws, & Scepansky, 2006). Slide text was built line by line in an uncluttered structure, and the slides were used as a springboard for discussion rather than a scripted monologue. Two such slides, which inspired a great deal of discussion, are shown in Figure 1.1 and Figure 1.2. Video clips were linked to the presentations and shown during appropriate times to facilitate in meaning making. The teaching assistant asked questions (including specially thought out questions for ELL students) throughout the introductory review. Often, the responses to these questions would result in student discussion. The discussion method "Think, Pair, Share" was also implemented, especially in the beginning labs when students were hesitant to share opinions.

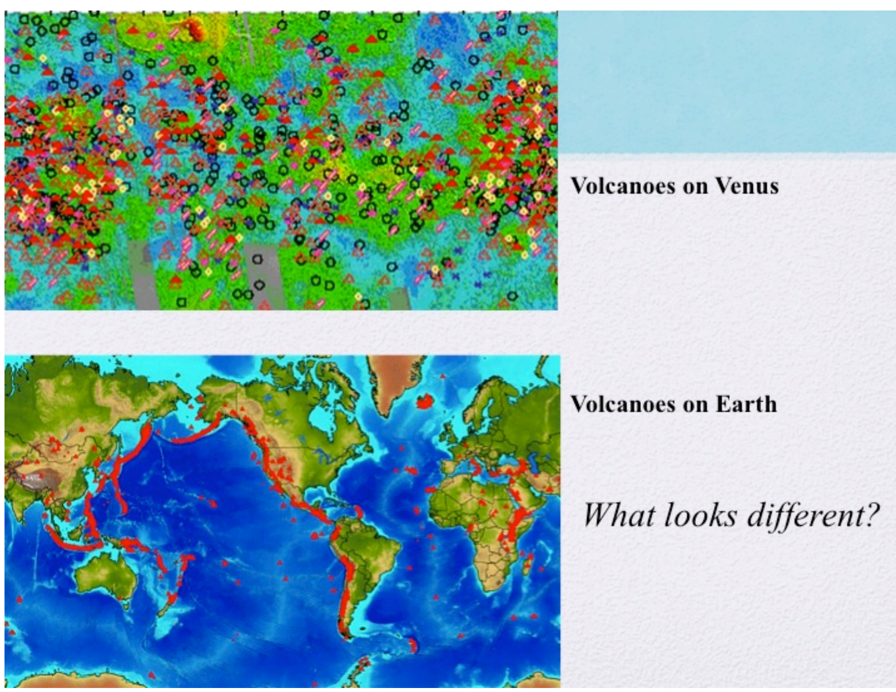

Figure 1.1 Discussion Slide from Plate Tectonics Lab

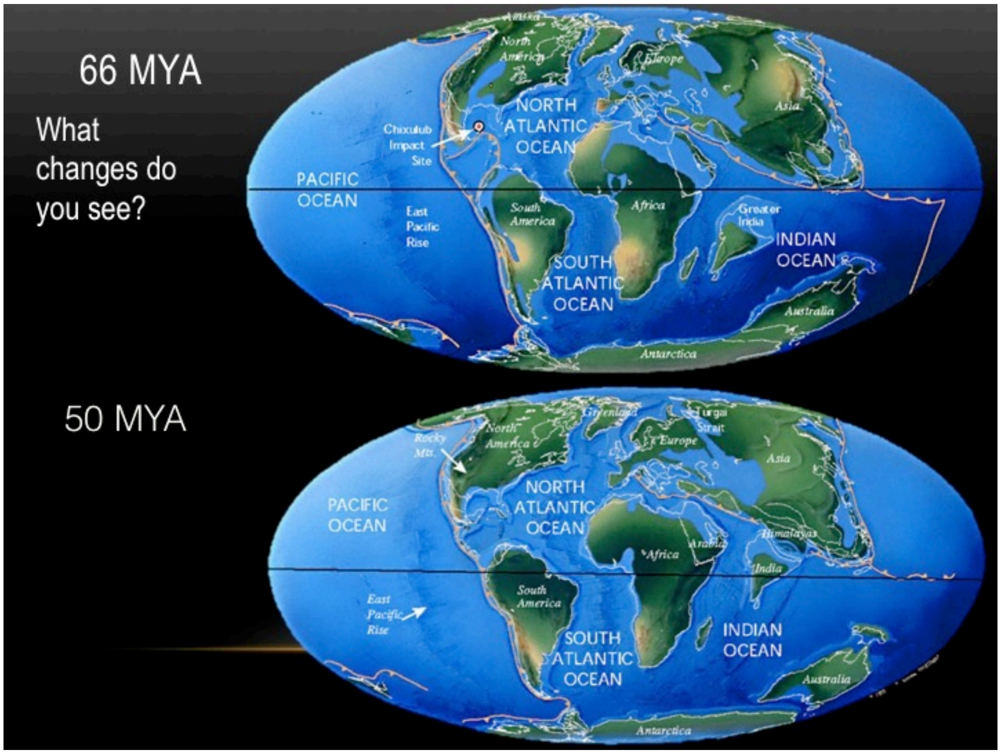

Figure 1.2 Discussion Slide from Cenozoic Lab

Handouts containing important information from the slides were passed out to students at the beginning of class so that the students could focus their energies on participating in learning rather than copying notes. These handouts contained concept maps, fill in the blank phrases, and other tools to increase literacy and facilitate studying later.

One or more activities followed the review. These activities were usually inquiry based and performed in groups of two to four, with the exception of a few whole-class activities. Activities involved the creation of some product such as a poster, and they concluded with the presentation of this project to the rest of the class. During many activities students were encouraged to use the Internet and other resources such as their book or books checked out from the public library. For example, during the igneous, metamorphic, and sedimentary rock labs, the TA checked out many books (picture books, identification books, topic related books) from the Lafayette Public Library for students to use during rock identification and poster creation.

A discussion followed the group presentations. Discussions often prompted students to compare the work of their group with the work of other groups. For example, during the Paleozoic Lab students were asked to create a diorama using a shoebox, construction paper, pictures from the period of the group's choice (periods were not repeated), and other materials. During the presentation they were asked to discuss the biosphere, hydrosphere, atmosphere, and geosphere of their given period. During the group discussion, changes between adjacent periods and over the course of the era as a whole were discussed. Figure 1.3 exhibits one such diorama.

The last portion of lab time was used as a "Summary Session" where students answered two to four questions in written form on handouts, and answers were turned in to assess whether or not students had understood the information presented during the laboratory time. These casual summative assessments included questions ranging the tiers of Bloom's Taxonomy, but most called upon higher order thinking and required thoughtful answers for full credit. The levels of Bloom's Taxonomy include remembering, understanding, applying, analyzing, evaluating, and creating (Krathwohl, 2002). Many of the questions asked students to apply knowledge learned during class, analyze and compare data, and pull together complete ideas from a set of information. A few questions could be considered from the evaluating and creating levels because of their open-ended nature. Students understood that their responses would be graded on an individual basis, and they could choose to support their answers in a different medium (verbal communication with the TA, drawing pictures, or constructing graphs or tables). Example questions along with their associated level of Bloom's taxonomy are listed in Table 1.3.

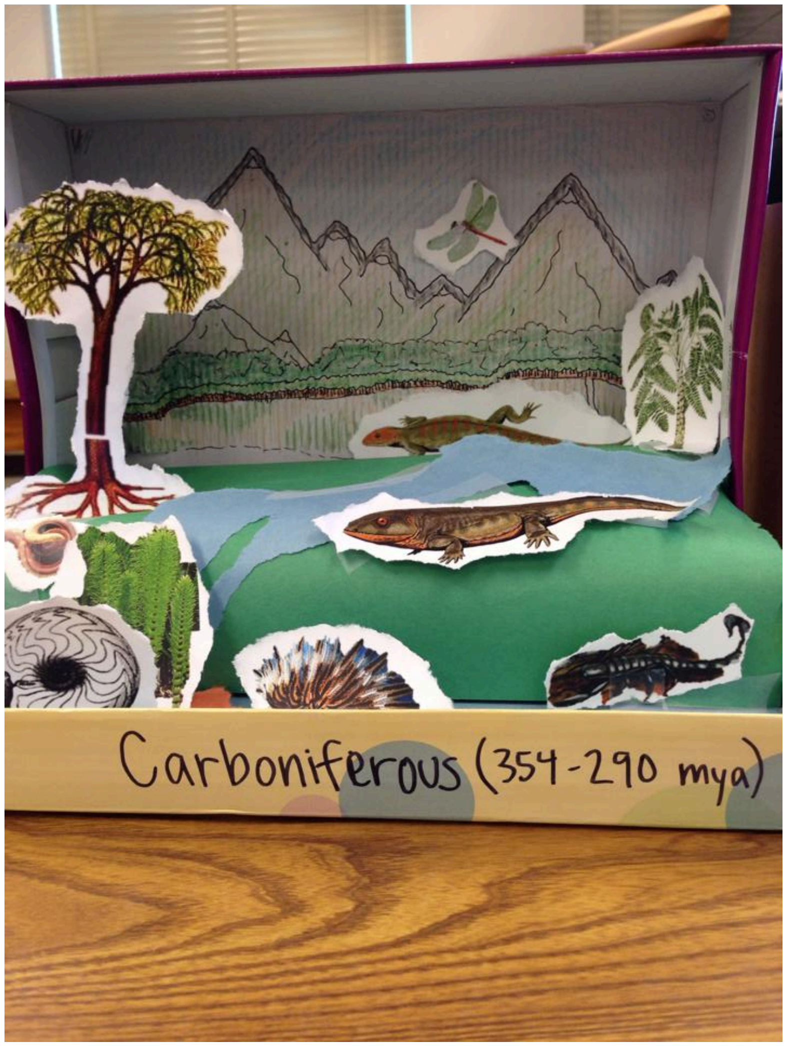

Figure 1.3 Diorama for the Carboniferous Period

Table 1.3

Example Questions as Part of a Laboratory Summary

Question	Level of Bloom's Taxonomy
Give an example of a divergent continent-continent boundary and a divergent ocean-ocean boundary.	Remembering
How can you tell which rocks are intrusive and which are extrusive?	Understanding
Using the principles and laws discussed in class, write a story telling me what happened to form this cross-section.	Applying
Pick an era of the Precambrian that belonged to another group today. Compare and contrast it with your era.	Analyzing
A geologist finds a dinosaur bone in a limestone bed. She would like to know if this bone is younger or older than other similar bones found in another part of the world. What should she do?	Evaluating
How can we use modern technology in learning about plate tectonics?	Creating

1.4 Specific Modifications and Method of Modification

Each laboratory lesson was modified to incorporate more effective learning and teaching processes. Since the lecture component (including lecture exams) was not modified alongside the laboratory component, specific content topics remained fairly constant in the labs. In order to maintain continuity of topics from previous years, the previously used laboratory packets were worked through and scanned for their most important concepts. These concepts were noted, and incorporated into the new structure. Often, the breadth of covered material was shortened, but the depth to which the chosen material was covered was increased. This change was inspired by the structure of the Next Generation Science Standards, which place more emphasis on the depth of student understanding of a few very important foundational concepts.

The previous semesters' labs were, in a sense, "teacher-proof". Teacher-proof curriculum has long been a staple of western education since early reform movements in the 1960's, and it has encouraged the packaged nature of science education. In theory, a teacher-proof curriculum can be taught by anyone, but in practice, this is rarely the case (McDonald, 2010). Thus, the course's packet pedagogy was discarded, and a three-part structure was adopted for the lessons. Warm-ups and introductory short lectures prepared the students for the main activity by reminding them of what they had learned in previous lessons. The main activity gave them time to explore their ideas and connect new material to their existing framework of knowledge. Finally, the summary portion allowed time for students to reflect on what they learned during the lesson and applications of that new information.

1.4.1 Lab 1

The first lab topic, the scientific method, was a challenging lab to change. For many years, the lab packet had consisted of information surrounding Kentland Crater in nearby Newton County. The students would read and complete questions within this packet. Recent literature has supported the teaching of argumentation rather than the scientific method, as this supports realistic student understanding how scientists practice science (Berland & Hammer, 2012; Berland & Reiser, 2009; Erduran, Simon, & Osborne, 2004). However, because the literature had not been thoroughly read by this point in the semester, the scientific method was still taught as a structure to follow while planning a study. It was emphasized that this was a very simplified model for how scientists work, and students were encouraged to add or repeat steps in the process if necessary during the activity. In the future, this transformation will be enforced and the goal will be for students to develop their abilities in sense making, articulating, and persuading as suggested in the literature (Berland & Reiser, 2008).

The purpose of the first lab was not simply to review the scientific method. For our purposes, it was also to familiarize students with what would be expected of them in an active learning setting, a practice not many of them were accustomed to in a university environment. After a review PowerPoint, each student was given a strip of paper that contained a single phrase. These phrases included observations, hypotheses, testing methods, and rejections/acceptances of hypotheses all concerning how the crater at Kentland was created. Students had to organize themselves in a line based on what order they believed told a complete story of the scientific process at work from the first observations to the acceptance of the site as an impact crater. For students to complete this task, they quickly discovered that they needed to talk to each other, attempt to organize themselves, and test their ideas. After they believed that they were in the correct order, each student across the room read his or her phrase.

After this activity, the students were divided into groups of four or five, and were given an "inspiration sheet". These were prepared handouts with "data" on them including pictures, tables, news, etc. The students were asked to review and discuss the data, and come up with a question based on their observations. Then, each group needed to make a poster covering all the steps of the scientific method up until accepting or rejecting their hypothesis (since they could not actually test their hypothesis). The three data sheets addressed water on Mars, sand dune origins, and caves in Indiana. After completion, each group shared its poster, and groups that covered the same topic, compared how they, starting with the same data, had come up with different questions and hypotheses even though they had often made similar observations.

During this first experience with active learning students struggled with expressing observations they had made, and many were confused about what would in fact "qualify" as an observation. They hesitated in communicating their uncertainty, and they seemed reluctant to confide in their group members about this confusion. This perplexity prompted a group discussion. Eventually, after presenting their work, students appeared more comfortable with the observations they had made.

To solidify the classes' understanding of the scientific method, a flashlight missing its batteries and bulb was passed around. The first few students were asked to make observations; in both sections, one observation was that the flashlight did not work. The students then hypothesized that the light did not work because it did not have batteries. They tested this hypothesis by adding batteries. When it was found that this did not solve the problem, students revised the hypothesis to include that the flashlight needed a bulb. When the light worked after adding the bulb, they accepted their hypothesis that missing batteries and bulb had prevented the light from turning on. This activity solidified the process they learned in class.

1.4.2 Labs 2 and 3

The second and third lab sessions focused on igneous rocks (2) and sedimentary and metamorphic rocks (3). Previously, the igneous rock lab had consisted of completing a packet and identifying twenty-two samples of igneous rock. The sedimentary and metamorphic rock lab had required twenty-five sample identifications as part of an eighteen page reading assignment. It was decided that for the students to truly grasp the rock cycle and the concept of rock formation, the number of samples would have to be reduced and the concept of crystallization would need to be covered more deeply. To increase relevancy for students, the warm up for the igneous rock lab was tailored to focus on modern uses of igneous rocks.

Students were asked if they had to take a step for every way they used igneous rocks (or minerals from igneous rocks), how far they could proceed down the hallway outside the laboratory classroom; guesses were short distances of no more than ten or fifteen steps. The TA then stood in front of the group of students, then in the hallway itself, and read from a list of various ways human life is impacted by igneous rock. After each phrase, students took a step. The students were surprised to see that they were able to make it all the way down a length of the hallway.

During the PowerPoint warm up, students practiced making observations about various igneous textures, and they also were shown a video of lava being poured over ice. The concept of crystallization was discussed and a concept map was completed. Students then learned how to use the map they created to identify igneous rocks. In pairs, the students made posters showcasing a rock given to them, which included the magma type the rock cooled from, whether it was intrusive or extrusive, its texture(s), minerals it contained, and its name. They were allowed to use the Internet and library books to look up an environment the rock may have formed in, its uses, and any other interesting facts. They drew at least two pictures: one of the whole rock and one of a section of the rock that exemplified the texture. Each group presented their poster, and the rest of the students to took notes about the rocks as they were presented. The posters were laid around the room while they did rock identification.

In the sedimentary and metamorphic rocks lab, students also completed a series of rock identifications after completing posters. In this case, posters focused on types of depositional environments like lakes, reefs, deltas, and rivers and the sedimentary rocks and structures formed in those environments. Much time was spent discussing the energy differences between environments and how these differences were connected to variations in rocks and structures.

Students concluded this lab by confronting their pre-conceptions of the rock cycle. When asked how they thought about the rock cycle, many students responded that it was a circle, where one rock type, like igneous rock, was transformed into metamorphic rock, which was then changed to sedimentary rock and back to igneous rock. A six sided die was passed around the room, and students were told that the numbers one and two represented sedimentary rock, three and four represented metamorphic rock, and five and six represented igneous rock. After each roll, students had to find a way to get from the previous rock type to the new rock type. At times, this meant moving from sedimentary rock to sedimentary rock or igneous rock to igneous rock. The idea that rocks could be recycled into the same form time after time seemed unfamiliar to the students, but since much of lab time was spent on formation processes, this sequence of formation was accepted as feasible. The resulting diagram (drawn from the sequence of die rolls) looked little like the circular rock cycle the students were used to, but it more accurately reflected their understanding of rock formation. A representation of this cycle is shown in Figure 1.4.

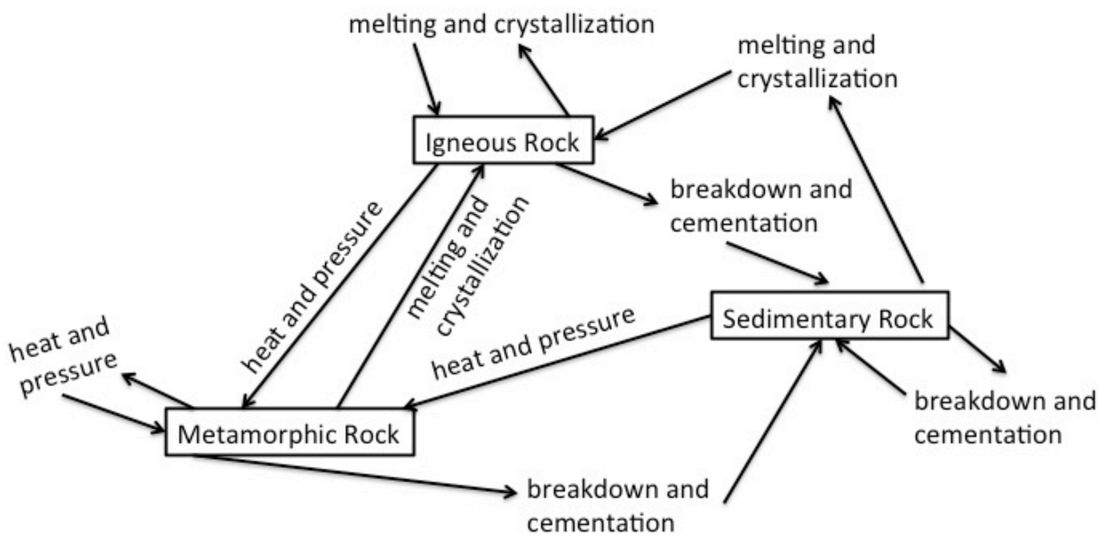

Figure 1.4 Rock Cycle Drawn By Students

1.4.3 Lab 4

By the fourth week of lab, students were accustomed to having to work together and communicate during activities. The first week, directions had been very specific for what should have been included in their presentation. The second week the directions were slightly more open-ended, and by the third week, the students understood that what was truly being required of them was energy, creativity, and effort. In a sense, they were presented with a challenge to pour their talents into, not a mold.

For this lab, the students were told that they would be provided little direction, but that this hands-off approach was purposeful. Groups of four or five were given a map of South America and the Pacific Ocean, a shoebox, tape, scissors, colored pens, a table of earthquake latitudes, longitudes, and depths, strips of paper, and tape. The introductory review consisted of reminding students about the types of plate boundaries and paired sketches and definitions of the terms focus and epicenter. The groups were asked to use the material provided to determine what type of plate boundary was shared by South America and the Pacific Ocean. They were also told that the data table they had been given was real data, information that seemed to get them excited about the task.

This activity was based on the lesson “Real Evidence of a Subducting Plate” from the Geological Society of America’s secondary level lesson plan database. Originally, the activity was meant for high school students, but it also provided step-by-step instructions for students to construct their model and find the solution. To modify this activity for college students, groups were asked to come up with a plan for how they were going to construct a model of the crust at this plate boundary. Almost all groups constructed their models similarly to the suggested method in the original lesson plan (Figure 1.5); however, there were some groups who had interesting modifications.

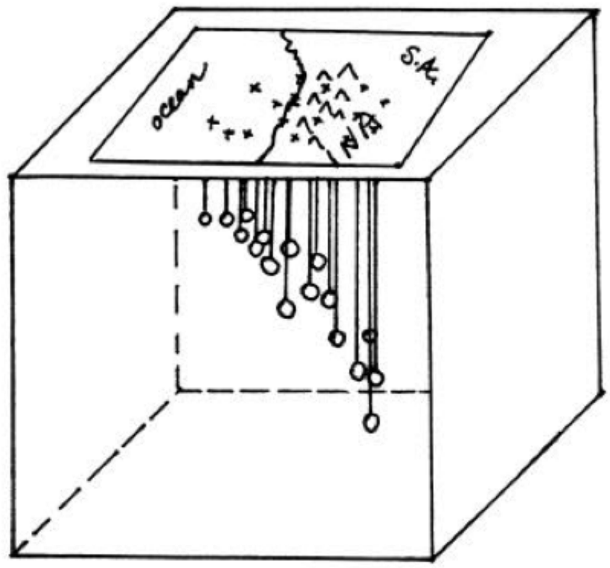

Figure 1.5 Model of Crust Showing Depth of Earthquakes

By the end of the lesson, the groups had created models to answer the question of what type of plate boundary was present. During the lab, students worked together, problem solved, and negotiated their method of construction and meaning of the model they had made. Since all groups concluded the boundary was a subduction zone, discussions focused on what the surface created by the depths of the earthquakes symbolized and how they could determine the rate of subduction. Many ideas were brought up concerning the second question; for example, one group suggested planting locating devices in the ocean floor and tracking their movements on Google Earth. Another group suggested finding historical data with specific dates and using those dates to calculate rate. When the students were asked why the earthquakes eventually did not occur at inland longitudes, the discussion really heated up. Students began to question how plates actually subduct, how this process is connected to the plate they are subducting under, and what happens to the plate once it is part of convection in the mantle. This became the perfect setting for confronting the common misconception of the mantle as being made from liquid magma, and since students had spent the class putting the scale of processes in perspective, they seemed more comfortable assimilating the idea of a plastic mantle.

In past years, this lab again consisted of students completing a packet using their textbooks. Instead, during this semester, it emphasized technology, communication, problem solving, and innovation.

1.4.4 Lab 5

The previously used packet for lab 5 concerned absolute and relative dating with a focus on terminology. It asked students to relatively date rocks in cross sections, correlate across stratigraphic columns, and list half-lives and decay constants. In the renovated lesson, terminology was still covered although as part of the introductory PowerPoint. Students were given the technical definitions for words like formation and member, and asked to negotiate in groups working definitions for these terms. Most of the lab focused on developing the concepts of relative and absolute dating from intuition and information from students' lives.

For a warm up, students were presented with the slide shown in Figure 1.6 and asked to come up with ways to put these people in order from oldest to youngest. Ideas

Figure 1.6 Warm Up Slide for Relative and Absolute Dating Lab

ranged from asking them all for their drivers licenses (to see their birthdays) to asking each person how old they were to inspecting each face for signs of age to ordering by height. The students were asked which methods were best and why; for example, if no one is carrying their drivers license, is asking to see them a viable option? Students noted that some methods used numerical results and some did not. Methods that used specific birth dates gave the students more information like how far apart in age individuals were, while other methods, like simply asking the people to order themselves, only gave a relative set of ages (one individual is older that the individual to their side).

After this warm up, the group reviewed concepts assigned as definition work in previous years such as types of unconformities. They were shown a video about the Grand Canyon, and then, having been given a generalized cross section of its rocks, discussed in groups where certain types of unconformities were located. These locations were collected as a whole class and confirmed by each group.

For the activity, groups of three were given tape, scissors, crayons, markers, and construction paper. They were asked to design a cross section implementing at least three of the concepts discussed such as unconformities and crosscutting relationships. Once the cross sections were complete, groups presented them to the class, communicating the order of formation in their cross section. After the presentations, two cross sections were chosen. The teaching assistant ran tape along two vertical lengths on the backs of the cross sections and cut two vertical segments held together by the tape. A magnet was used to hold these segments to the white board. The teaching assistant used a white board marker to show the students how to correlate stratigraphy using one set of stratigraphic columns. Students were then asked to negotiate meanings in their groups for the terms stratigraphic column and cross section. After doing this, they, as a group, completed the correlation of the second set of stratigraphic columns on the white board.

To learn about absolute dating, students were first shown a video discussing the different types of particles released during radioactive decay. They then used a Java applet to play with particles experiencing radioactive decay, noting any patterns they noticed. The applet allowed them to release up to 100 particles into an environment, and it counted the number of parent and daughter atoms present at various times (first, second, and third half life) during the process of decay. Students were then presented with the decay formula and were given the opportunity to calculate how many parent atoms would be present (starting with 100) after one, two, and three half-lives. These values were graphed, and it was agreed that the applet indeed mimicked this relationship of decay.

Students were given extra time to play with various functions of the applet before they completed their section summaries. The next lab period was used for the first exam, which will be discussed in the assessment section below.

1.4.5 Lab 6

This lab covered material concerning the concept of evolution. In previous years, these topics had been covered in lab 7 and the origin of time and the Precambrian Era had been covered during lab 6. However, since life developed in simple forms during the Precambrian, it was decided that evolution should be taught before the development of life was discussed. The original lab packet had contained definitions of terms and identifications of people, along with the construction of cladograms, diagrams that show evolutionary relationships among organisms. In contrast, the new lab would emphasize human impact and connection to animal and plant evolution, with a short activity about the historical aspects of evolution.

As a warm up, students were paired, and each pair was given a sticky note with a name or phrase written on it. Some of these included Charles Darwin, Scopes Trial, Kitzmiller v. Dover Area School District, and Phillip E. Johnson. Students were asked to take just a few minutes to learn about these individuals, cases, or topics, and describe their findings on their sticky note. A timeline was drawn on the board, and once students had completed their note, they placed it on the timeline in the appropriate place. The purpose of this activity was to confront an issue that cannot be ignored in teaching evolution- the controversy that has been always associated with it. By using the sticky notes to create a timeline on the board, students visually understood that creationism had not been scientifically accepted for over one hundred years. This activity was kept short, and it was closed with a short disclosure by the teaching assistant that there are many ways of knowing something, and that in lab, science would be used as the prominent way of knowing.

During the introductory review, three short videos were shown which highlighted evolutionary changes in the ocean around a reef and in a rainforest. Although the first rainforest video pertained to evolution of a fungus, the second concerned the evolution of the Lyrebird, whose mating calls are compilations of imitations of common noises in the forest. When the bird began to imitate camera shutters and chainsaws, the students were shocked. Audible gasps were heard around the lab room, and many students were visibly upset that deforestation was impacting the mating of such a fascinating creature.

The rest of the class time was spent on creating cladograms. The first cladogram, constructed as a class, was a simple coin cladogram. The teaching assistant passed out a nickel, penny, quarter, and dime to each group of students, and asked them to brainstorm what features the coins had in common. These features were written these on the board and used to construct a table of shared characteristics. From the table, the teaching assistant helped the students build a cladogram.

After this activity, the importance of zoos as research facilities and as mechanisms of public awareness was discussed and related back to the Lyrebird's situation. As it turns out, Lafayette has a free public zoo to educate its citizens. Many students were unaware of this fact. Groups used the zoo's website, which had a page dedicated to each of its unique creatures, to construct cladograms and characteristic tables. These cladograms were presented at the end of lab.

1.4.6 Lab 7

The packet for this lab, concerning the origin of time and the Precambrian Era, covered a particularly wide range of topics, from prokaryote and eukaryote development to the Big Bang Theory to divisions of time. Two questions asked students to define sixteen terms using their textbook. Questions like these belong to the lowest level of Bloom's taxonomy and are extremely frustrating for students to complete. Many students tend to think of the Precambrian as an irrelevant, boring era when in fact, this era sets the stage for the rest of Earth's development. The renovated lab would still cover the divisions of the Precambrian, but in such a way that a picture of the era as whole could be developed. To do this, the concept of the four major systems of Earth, the hydrosphere, atmosphere, geosphere, and biosphere, was introduced.

Eight periods of time were assigned to students in groups of two to three, and each group was assigned a time period. These time periods were: Eoarchean, Paleoarchean, Mesoarchean, Neoarchean, Paleoproterozoic, Mesoproterozoic, Neoproterozoic, and Edicarian. The activity, inspired by "Expedition to the PreCambrian", a lesson from the Science Education Resource Center at Carleton College, required each group to design a page for a field trip guide. The page would need to address aspects of the four systems of earth and include the years associated with the period. Students were given a list of terms (which were required for definition in the previous year's lab) such as Stromatolites and Rodinia. If the students came across these terms in their reading about their time period, they needed to include them in their page. To help students conceptualize what a field trip guidebook looked like, guidebooks from previous trips taken by the teaching assistant were passed around the room.

After creating their pages, groups presented their pages in order from oldest to most recent period. The teaching assistant took notes on the white board during these presentations, which had previously been marked with a timeline starting from 4.6 billion years ago at one side of the board to today on the other. As groups presented, their period name and its description fell in place on the time line. After all groups had presented, the pages were stapled into a field trip guide to be used for studying later. Students took notes on a pre-formatted hand out as other groups presented. During the discussion, students were asked to tell the "story" of the Precambrian in various ways. For example, one group was asked to tell the story of the biosphere while another was asked to tell the story of the geosphere. This reinforced the idea that geologists use rocks to tell a story of Earth and that what we put into the Earth, will eventually create rocks and tell a story about humanity. It was also discussed that although changes (such as evolution) happen, these changes are strung together, connected like beads on a string.

1.4.7 Lab 8

During this lab, students were to work in pairs. To facilitate in pairing students, each person was given a piece of paper with a percent parent atoms or a percent daughter atoms in a sample. Students had to find the individual with the complementary percentage to their own particular percentage. They would need to calculate the age of their particular sample, and then use the guidebooks or notes from the previous lab to find what period their sample was from. After doing this, they were asked to line themselves up in order from the group with the oldest sample to the group with the most recent sample. The review PowerPoint contained a single slide representing each period of the

Paleozoic era. These slides reflected the format students had developed in the guidebook pages during the previous lab.

A few students had recently taken a trip to the Field Museum in Chicago, and their trip inspired the main activity. The class as a whole would recreate the diorama exhibit, which showcased a scene from each period of the Paleozoic, from the Field Museum, in the classroom. Each group was given construction paper, a shoebox, tape, scissors, and two pages of photo-shopped images of plants and animals from the time period. They used these materials to construct dioramas, which were then placed side by side from Cambrian to Permian at the front of the room (see Figure 1.3 for example). Each group presented their diorama to the rest of the class, and then, as a whole, the class "visited" their Field Museum exhibit. Changes between adjacent periods and across the era as a whole were the focus of discussion.

This lab changed drastically from its previous condition. In past years, the Paleozoic was covered in two lab periods. During the first session, students were given a Kentucky Geologic Survey publication "Exploring the Geology of the Cincinnati/Northern Kentucky Region" and asked to find certain facts throughout the paper. During the second session, students were to identify twenty-seven fossil specimens by class and phylum using the symmetry exhibited by the specimen. The radical renovation of this lab in particular was inevitable as it was felt that students would remember little information from the previous format of the lab. In fact, one student who had a friend who had previously taken the class, told the teaching assistant that the previous years' students memorized the material to pass the test and soon forgot what they had "learned". This was a pattern that could not bear repeating.

1.4.8 Lab 9

Lab 9 content focused on the Jurassic and the Triassic periods of the Mesozoic. Previously, this lab had additionally covered the Cretaceous; however, it was felt that since such drastic changes happened during the Mesozoic, biologic changes in animals would be covered in the first section (Lab 9) and a second section (Lab 10, discussed below) would be used to facilitate learning about the Cretaceous and plant life, climate, and plate tectonics of the Mesozoic.

During the warm up, students reviewed terms from the previous lab by playing bingo. Definitions were drawn from a shoebox, and the group had to figure out what word was being defined. The game was played until every student won and received candy. At the conclusion of the PowerPoint review, parts of a NOVA video called "the Real Jurassic Park" were shown. This video addressed whether or not it would have been possible (or eventually would be possible) to actually clone dinosaur DNA.

For the lab activity, the group assumed that this was possible and that as a class, pairs of students would prepare possible layouts of a prehistoric park with animals and plants from either the Jurassic or Triassic to present to a wealthy investor. After each group had completed their park map, they would have to describe the animals and plants found there on the back of the map. A large table was made on the white board as shown in Figure 1.7. Students would add information from their park to this table. As a whole class, the differences and similarities between the plants and animals of the Jurassic and Triassic were discussed. These trends were also compared and contrasted with animal and plant life during the Paleozoic.

	Plants	Animals
Triassic		
Jurassic		

Figure 1.7 Table for Students to Complete During Mesozoic Lab I

1.4.9 Lab 10

As mentioned above, previously there had only been one lab session concerned with the Mesozoic. Thus, in past years, lab 10 contained content about the Cenozoic Era. Isolating a single period, the Cretaceous, for an entire lab session provided abundant time for discussion and student work. Similar to the Plate Tectonics lab, this lab provided the students with room for intellectual creativity and risk taking.

This activity stressed the inter-connectivity of the movement of tectonic plates, climate, and evolution of life forms. In pairs, students received modified maps from the PALEOMAP Project representing the Upper and Lower Cretaceous. These maps were be marked with the locations of certain rock types, and each of those rock types was associated with a specific type of climate. Pairs were provided with a key that displayed this correlation. Students were first asked to outline boundaries for certain climates and label the regional climates as Tropical, Cool Temperate, Cold, Warm Temperate, or Arid. This could be completed on the map itself or on tracing paper provided.

They then observed maps of angiosperm and gymnosperm fossils from the upper and lower cretaceous (Peralta-Medina & Falcon-Lang, 2012), and attempted to copy these locations onto the proper climate maps or onto a separate piece of tracing paper. By combining the two sets of maps, pairs could hypothesize about the connections between tectonics, climate, and the evolution and domination of angiosperms. They discussed how the distributions changed with time and with movement of the plates, and how the evolution of bees and abundance of herbivore dinosaurs may have played a role in angiosperm growth and spread. Pairs chose different ways to represent regions and plant life, but all came to the same conclusions. As a session summary, each student wrote about how this activity displayed the connections between the biosphere, geosphere, hydrosphere, and atmosphere of the Cretaceous. By this point in the semester, "connections" had become an important theme in the lab.

1.4.10 Lab 11

Lab 11 covered the Cenozoic Era, which included the formation of the Himalaya Mountains, the beginning of the Arctic Circumpolar Current, the evolution of mammals, and glacial stages of North America. Instead of using the students' abilities to look up answers as the backbone for this lab, their understanding of plate tectonics and its relationship to climate (developed during lab 10) was employed. In lab 4, students conceptualized plate tectonics differently than they had in the past; no longer were the Earth's crust an immovable giant and the mantle the inside of a volcano.

While passing around an empty pop bottle, the students were asked what happened if the plastic of the bottle was pressed down. They were told that this part of the warm up was not a trick question, but would lead us through some thoughts about the crust and mantle. The students responded that the plastic bent inward when pushed. They were asked what would then happen to the bottle if they pushed with less force, and quickly, they answered that the plastic would move outward. The group was asked to "think, pair, and share" about why this happened, and most individuals shared that it happened because nothing had changed inside the bottle. The air was still pushing out. Finally, they were asked that if the bottle were an analogue for Earth (the plastic being the crust and air the mantle) what did that mean large mass concentrations like mountains and glaciers did to the crust and what did that imply happens when these bodies are melted, moved, or eroded away. This discussion appeared to get the class both confused and excited, with many students surprised that the crust could be pushed in like a finger could push in the side of a pop bottle. During the introductory review, the teaching assistant taught a simple lesson on crustal rebound and how it related to the pop bottle analogy.

A review of the time periods and epochs of the Cenozoic era was also included, but when the slide for the Quaternary period popped up, it mentioned very little about climate. The students were instructed that instead of being told about the climate of the Quaternary, they would need to figure it out for themselves. They were told that although some scientists use ice cores to learn about paleo-temperatures, they would use foraminifera (pictures of foraminifera were displayed). This short activity was inspired by the activity "Climate Analysis Using Planktonic Foraminifera" found within the teacher resources pages of the website for the University of California Museum of Paleontology (Olson, n.d.). Students were told that the foraminifera shell's direction of coiling is correlated with ocean temperature, and they were given a table of the numbers of left and right coiling foraminifera in fossil beds dating from 160,000 years ago to 10,000 years ago. They used these numbers to calculate the percent of right coiling shells, graph this percentage, and determine, using their graph, when the climate was cool or warm. After they completed their small graphs, the class as a whole graphed its results on the board, labeling glacial and interglacial stages, and deducing that today, the Earth is in an interglacial stage.

The final activity for the lesson combined what students had just learned about crustal rebound and glacial activity in North America. They were presented with a copy of a section of a blog, a map of changes in glacial activity in the Great Lakes area over the last 20,000 years, a map of rate of crustal rebound of this region, a depth profile of the Great Lakes, and an image from Google Earth showing the location of the blogger. The blogger was complaining after returning to his hometown of Six Lakes, Michigan after many years, the lakes and rivers of his childhood had gotten shallower. After doing some historical research, he had found that over the course of the history of Six Lakes, the bodies of water had in fact become less deep. Thus, he consulted a geologist who informed him that the crust beneath his hometown was rebounding. This conclusion from the blog was not given to the students. They were asked to review the maps and consider the pop bottle experiment from the warm up in order to compose a response to the question posed in the blog in teams. The replies were turned in as the session summary for the lab, and all were very thorough and thoughtful.

1.4.11 Lab 12

Because of university regulations on when finals for lab sections can be taken, the second exam was taken between labs 11 and 12. No information on the content supposed to be learned in lab 12 was provided, so it was decided that this lab would be used to consider the Anthropocene and the future of Earth. The students were presented with the following scenario: Fifty million years from now, long after human beings are extinct, an alien race skilled in geology comes to Earth, and finds the geologic record of the Anthropocene. They were asked to consider what these rocks would look like, what would define the beginning and end, and how they felt about what the aliens would find. This sparked an intense discussion that challenged students to recognize that each one of them has an impact on the state of the planet. Responses included that the aliens would find paleosols with evidence of farming, and that across the North American plate they would find sedimentary rocks made from building rubble and a layer of fossilized humans all at the same depth (fossilized cemeteries). Although it seems like a morbid discussion, the students seemed fascinated by this possibility.

After this discussion, the class read two articles on climate change during the Anthropocene and talked about what climate change actually means. An atmospheric sciences graduate student joined the discussion as an “expert” to help answer questions the group had. Once the group had finished their short course in understanding climate change, the remainder of class was used to set up a Google document to facilitate studying for the lecture component final.

1.4.12 Field Trip to Delphi Quarry

Similarly to the packet assignments for lab, the required work of the students during the field trip was to complete a packet of questions that could be answered by listening to the lecturing professor lead the field trip. This trip consisted of a visit to nearby Delphi Quarry, Prophet’s Rock, and the site of the Battle of Tippecanoe (among other stops). Because the lab was reformatted to be student-centered, it was decided that the field trip would be student lead. Recalling what they had learned during lab 7 (Precambrian) about guidebooks, each pair of students designed a page for a field trip guidebook to be used on the trip to Delphi Quarry. Topics included pollution in the Lafayette area, Lafayette's drinking water, construction on campus, the practice of quarrying, and many others. Pairs chose a topic, and upon completion, sent their page as a word document to the teaching assistant who compiled the pages and had guidebooks printed in color for the students. During the field trip, each pair presented their page to the rest of the class. This method of student lead field trips has been supported as effective in the literature (Todd & Goeke, 2012), and it seemed to work very well with the two sections of students.

1.4.13 Assessments

Because the laboratory lessons were so greatly modified, both the assessment style and content of assessments had to be changed as well. Students had been required in lab to think creatively and critically, and therefore, they were assessed with questions that called upon the higher order thinking skills they had developed.

In the first exam, students used live streaming data from Japan to examine earthquakes along its coast. They were asked how they would use this incoming data to create a model or design an experiment to explain what kind of plate boundary movement was causing these quakes. In another question, they were asked to design a post card from any depositional environment and provide specific information about that environment like the types of sedimentary rocks that form there and what type of environment (terrestrial, marine, or transitional) it was. Given a map of South America and Africa that showed similar fossil types on both continents, students were asked to use this data to support the theory of plate tectonics. Because rock identification is a mandatory part of the exam, students were also asked to identify twenty rock samples compared to thirty samples in previous years. The first two questions of Table 1.1 are characteristic of the types of questions asked on the previous years' exam. These questions tended to ask students to recall very specific details and complete a "matching" section. Very few questions asked students to draw a diagram in support of their answers.

In the past, the second exam exhibited a similar format. Students were required to complete three pages of fossil identification (from pictures), giving the proper name and phylum for each fossil. They were also asked to define many listed terms, people, and types of dinosaurs, complete a cladogram given a characteristic table, and recite the binomial classification for humans. One question required students to list time periods in order, and again, this exam had a "matching" section. A student admitted to the teaching assistant that a completed version of this exam had been passed down in his group of friends, but that the highest score achieved on it was a sixty-nine percent. This assessment tested little more than the students' abilities to memorize facts, so a new lab final was designed that challenged them to not only remember, but apply the material they had learned.

The first question (separated from the rest of the exam) asked the students to work together, using appropriate resources to complete a diagram of the systems of Earth during the Paleozoic. Students were asked to list the sources they used, and it should be noted that no students used Wikipedia. Many used their textbook or websites used during class such as the website for the Field Museum in Chicago or university websites. In another question, students were asked to explain how microevolution, macroevolution, natural selection, and adaptation were connected. Although this may seem like a surficial definition question, it asks students to go beyond the meaning of the terms and uncover relationships between them. Many questions asked students to make connections between concepts learned during lab, and support these connections with factual knowledge. Questions also asked students to think about how they could use what they had learned during class in their lives. For example, one question asked students to imagine themselves on a hiking trip on a trail that followed a river. On both sides of the river they noticed that the rock layers seemed to line up. They needed to explain to their friend how they could create a picture of what the rock looked like before the river eroded so much away, drawing a picture to help explain.

Almost all questions included some kind of graph or accompanying image. For one question, students were asked to create a cladogram and characteristic table given five objects. These objects included a marshmallow roaster, fork, spoon, screwdriver, and spatula. Although they were not animals, testing this concept with tangible items instead of pictures allowed students to pick up the objects and inspect them for details. It also proved beneficial for English language learners, as they were able to describe the objects without having to know specific words for characteristics. Another form of question that helped these students in particular was a question that was required to be answered orally. A student, when ready to answer this question, would go to the hallway with the teaching assistant who would listen to his or her response and ask more probing questions to truly understand how well the student understood the material.

The number of questions on the lab final was reduced from forty-four to ten; however, the amount of time required to take the exam was maintained. It was felt that although the number of questions was much fewer, the time allotted to complete each question on the new exam was greater because they required students to think more deeply in order to receive full credit.

1.5 Methods of Study

This research study was approved (and granted exemption) by the Institutional Review Boards and Human Research Protection Program. Students participated in the laboratory sessions just as they would normally be required. They attended a two-hour and fifty minute lab once per week for fifteen weeks. The differences between this semester's lab and previous semesters' labs pertained to the way the material was taught and understanding was assessed, as discussed in the above subsections. We hypothesized that using improved teaching methods would result in an improvement in student attitude and cognition in Earth Sciences. Attitudinal changes were assessed with surveys, while the laboratory exams assessed cognitive development.

The students took two exams (a lab midterm and lab final), which were formatted with inquiry-based questions instead of the rote memorization questions of previous years. They were also asked to complete a survey near the beginning and end of the course, which assessed their belief in their abilities to make informed decisions concerning geoscience, to locate accurate information to aid in decision making, to retain the ESLPs, and to maintain a sense of responsibility and appreciation for Earth's condition. Students who participated in this study allowed us to use their exam scores to gauge the effectiveness of this teaching style. Students who chosen not to participate in this study still took the exams and surveys, but their exam scores were not used to evaluate the teaching method. Participation in this study did not affect their grades positively or negatively. They were not given extra credit or denied points due to their participation or lack there of. Because surveys were completely anonymous, all student surveys were used in evaluation of changes in attitudes.

Since constructivist methods are not considered unusual and have been shown to be effective, students were taught in this style regardless of participation in the study. As a requirement of the course, they attended the laboratory session, completed activities (including the surveys), and took the two exams. Students were informed of these requirements during the first laboratory session. They received a syllabus reiterating these requirements and an information sheet explaining the study more thoroughly. Students were notified that the teaching assistant was going to utilize a different but effective teaching method, and that we, with their permission, would use their test scores and two surveys to support or refute the effectiveness of this method. It was be clearly stated in the syllabus and vocalized that participation was voluntary and that no names or any other identifying information would accompany their responses to student surveys.

Exams were kept in a locked file cabinet in HAMP 4169, the office of the teaching assistant. After being graded, exam grades were uploaded to Blackboard for the students to access. Students who signed a consent form the first day of lab had their exam grades recorded separately as well in an excel spreadsheet on a password protected computer. Participating students were assigned a randomly generated three-digit identifier, which was associated with their grade. The key code for these identifiers was written in a notebook and kept in a separate locked file cabinet in HAMP 4169, only accessed when recording grades. The key code was destroyed once both exams had been taken, restoring anonymity to the participating students. Since the three digit identifiers were randomly generated, there was no need to destroy this data.

No names or identifiers were written on the surveys. Until recorded, surveys were kept in a locked file cabinet in HAMP 4169. Once data was transferred to an electronic format, surveys were shredded. The survey distributed to the class can be found in Appendix A. Students were asked to circle a number one to five to indicate how much they agreed or disagreed with the ten phrases on the survey. Average scores for agreement of each phrase on the pre- and post-surveys were compared using a one-tailed unpaired t-test.

Exam scores for those students who participated were used with a one-tailed paired t-test to measure if cognitive changes were statistically significant. It should be noted that the two exams were not, in a traditional sense, pre- and post-tests. The first exam tested material from the first four labs, and the second tested material from the remainder of the labs. We expected that an improvement in scores therefore would not only show an improvement in the amount of material learned, but also in the students' ability to think critically and to solve problems. To compare the results of the entire group of students, (those who participated and those who did not), a one-tailed unpaired t-test was used.

CHAPTER 2. REVIEW OF RELEVANT LITERATURE

2.1 Introduction

To teach Geoscience is a process of complex reconciliation. It is accomplished via the purposeful introduction of contradiction- that we are infinitesimal specks on both the clock and blanket of the Universe, but that all of our actions collectively alter the state of our planet. Spatial and temporal scales in Geoscience are barely imaginable even for advanced students, and the intricate and ever-connected dynamic systems that operate on them add a rainbow of color to an already overburdened intellectual landscape.

Which theories are taught and why is the basis for multifaceted arguments, but they are pieces that have been approached and afforded concrete replies. The missing component, which is equally valuable for educators, is the “how”. Detailed suggestions for better Earth Science pedagogy are not as widely present as one might hope, especially concerning the abstract dimensions of the subject. Methods that have been suggested are appropriate for lower grade levels or if appropriate for secondary and post-secondary levels, do not detail a coherent pedagogy. Some approach abstract topics outside of Geoscience or address only one aspect (time or space) of abstraction, but again lack a completeness that would move students forward from all angles. This review concerns itself with the missing pedagogy of abstract Geoscience topics utilized with the young adult groups of secondary students and early undergraduate non-Earth Science majors.

2.2 The "What", "Why", and "How Not"

Plate tectonics, the water and rock cycles, matters of climate and climate change, the structure of the Earth, the evolution of life that shaped the Earth's surface, and above all our place in the Universe are a few of these concepts that present us with such a challenge. This is not just because they are billions of years in the making or because they operate over immeasurable and often reincarnated distance, but because of their interconnected and dynamic nature. While some products of these processes and concepts can appear concrete, the topics themselves remain abstract. Examples of effective pedagogy can be found in the classroom and the laboratory; however, none of these approaches are both comprehensive and cohesive. What is missing is a pedagogy that reaches both into the laboratory *and* the classroom. No literature found described teaching that incorporated inquiry, engaged students, and increased academic achievement in both settings.

With an ever-increasing population, the limited resources of Earth appear even more finite. The growth of society has changed the way humans respond to natural disasters and hazards, and the depth of research provided by advanced technologies has opened new pathways for learning about our planet. The social importance of studying Earth Science has cultivated standards for K-12 education. These standards can be found in the text *A Framework for K-12 Earth Science Education*, and they include Earth's place in the Universe, Earth's systems, and Earth and human activity (National Research Council, 2011). As the motivation for studying the processes of Earth grows, and the standards for literacy are established, the exploration of methods for understanding is becoming a necessity.

Multiple science curricula have been seen as vehicles for creating optimally informed citizens (Pinar et al., 1995). The Earth Science field is no exception. In 2008, the Earth Science Literacy Initiative, a group of experts in Earth Science, research, and education, convened to establish a set of Earth Science Literacy Principles. These nine standards and their constituent sub-standards define the lower limit of knowledge for the Earth Science literate individual, but as they are standards, they offer no direction at how we should arrive at educating such individuals. These principles stress the human impact on Earth processes and our understanding of natural disasters and natural resources, implying that cognition should lead to a sense of civic duty. The curiosity to understand the planet we live on is also addressed in the many traditional abstract principles included in the document such as plate tectonics, sedimentation, geochemistry, and geobiology (Wysesson et al., 2012). Presented as neatly bulleted items, rote memorization is certainly possible, but this does the world no favors. Meaning making is required for both application and retention, so by simply knowing these facts, our world is not improved (Ward & Wandersee, 2002; Arthurs & Templeton, 2009; Apedoe, Walker, & Reeves, 2006).

Although the "how" to teach remains elusive, the "how not" is abundantly clear. Approximately fifty-percent of college students are abstract thinkers, and many of these individuals self-sort into the science, technology, math, and engineering (STEM) fields. For the other fifty-percent, termed "concrete thinkers", hands-on and social experiences are the conduits for knowledge gain. These students learn best outside of lecture environments, in classes where lessons are inquiry-based (Lawson, 1993). When these students find themselves immersed in content-swollen introductory Earth Science courses, incessant lecturing only drives them further from science and further from understanding (Leonard, 1997).

Even students who self-select into the Geoscience field can have issues learning in the traditional classroom. In a 2013 study of students in a geographic information systems course, the Q-method was used to identify learning styles within the class. The Q-method is a research tool that requires participants to sort statements based on agreement or disagreement, thus outputting a worldview or attitude about the topic under investigation. When used to assess learning styles, it can provide instructors with an inside view into how their students learn best and which pedagogical choices could stretch student thinking. Three main learning styles were attributed to the 18 students tested: the lone pragmatist, the explorer, and the synergist. Although these learning styles differ in their likes and dislikes of activities like group work, all three groups learned best by doing and visualizing rather than by simply thinking about a concept (Hall, Jenson, & McLean, 2013).

Geoscience knowledge, presented as isolated facts to be memorized and regurgitated on tests, evades too many students. Opportunities for meaningful learning structured by coherent ideas are lost, and the conceptual frameworks that would be strengthened by a carefully chosen assortment of these facts are dismantled.

2.3 Attempts at Effective Pedagogy in the Classroom

Many Earth Science courses both at the secondary and undergraduate level incorporate a lecture based component and laboratory component. In an effort to stray from the traditionally ineffective lecture, many studies have analyzed the benefits of various teaching and learning strategies including the construction of organizational diagrams, case-based instruction, in-class demonstrations, an emphasis on modeling, group work, and appropriate, engaging assessment. These methods have been shown to increase student engagement and understanding of the material being taught, and they should be considered in the construction of an effective pedagogy.

Ward and Wandersee (2002) suggested a form of graphic organizer for deepening process understanding. Their research study focused on using a Roundhouse diagram to highlight the systematic nature of science not portrayed in the student textbooks. In contrast to the perceived isolation of Geoscience concepts, the Roundhouse diagram permitted students the opportunity to format new information in a well-organized and well-connected way. It was suggested that this heightened connectivity and organization would help learners create mental models of abstract concepts, and that these strategies for scientific understanding would impact confidence and decision making in class. The construction of Roundhouse diagrams was shown to be effective in increasing student achievement. The study also showed that misconceptions and prior understanding should not be ignored when new information is being disseminated to students. For all its merits, the Roundhouse diagram also does not incorporate a time scale component into the student understanding of process. This method was also suggested for middle school students, more precisely low achieving middle school students, and as such, it may not be age appropriate for older secondary students and undergraduates.

In 2009, Clark, Sibley, Libarkin, and Heidemann introduced a new method for teaching complex Earth Science systems to non-science major undergraduates. This technique, called CauseMAP, engaged students by requiring that they follow matter through Earth processes. These researchers acknowledged the assimilation issues students face when processes are not visible, apparent, or when they appear to be disconnected from previously learned concepts. CauseMAP provided a more coherent structure to the knowledge being acquired so that stationary stages of a system could be translated into steps in a dynamic process. The tools used for CauseMAP were a set of questions concerning the matter and the process transforming that matter, a method for tabulating the responses to those questions, and a box and arrow diagram constructed using the tabulation. This semi-graphical method proved effective in conveying the systematic nature of Earth Science processes, but it did not provide a method for displaying the interconnectivity of those systems. It also contained no aspect of time scale within the processes, a factor that adds striking complexity to most systems that would be taught using this method.

Another approach to effective pedagogy in the classroom is using a case-based format for instruction. Using this approach, students are presented with examples of phenomena and/or questions concerning these examples and explore these ideas to figure out consequential principles. This method of teaching has been shown to increase student engagement, critical thinking, and ease of implementing scientific principles. It uses as a driving force the curiosity that students have when they begin a course, and it sustains interest in the topics covered by giving them purpose. The investigation associated with a case-based approach also more accurately demonstrates to students the methods used by real geoscientists. Although common to other fields, this pedagogical method is not widespread in introductory geology courses (Goldsmith, 2011).

In 2011, Goldsmith researched the implementation of a case-based format with an introductory geology class at the selective liberal arts college for which he taught. Until this study, he had taught the class using a traditional three-part curriculum: age and structure of the Earth, then plate tectonics, followed by surface processes. At the start of each class, a short quiz was distributed and at least twice during the semester students were given hour-long exams consisting of multiple choice questions from all levels of Bloom's taxonomy: factual recall, definition of terms, interpretation of data, process-related questions, and classification of objects.

After discovering that the most commonly used textbooks followed the same curriculum order, noticing in practice that this order drained his students of curiosity, and accepting the discrepancy between this approach and the way geology is actually practiced, this professor modified the format of his course to approach six geological questions. These included, for example: Why is the Great Salt Lake so salty? And how do tectonic processes affect global climatic patterns in the Caribbean? Goldsmith's method of assessment continued as mentioned above. All concepts covered in the traditional format were also taught in the case-based format, but since not all applied to certain questions, they were taught to the students in a different order.

Goldsmith statistically compared the results of quizzes and tests of traditionally educated students and students taught using the case-based approach. Students in the case-based course did significantly better on classification, interpretation, and process questions, similar to traditionally taught students on factual recall questions, and worse on definition questions. The purpose for this worsening was cited as students spending more time understanding concepts and processes and less time studying definitions. He also tested the percent gain (or amount of learning) for his students using pre- and post-tests. In the case-based course, 46 of his 47 students achieved a medium to high level of learning, meaning that their post-test scores were much higher than their pre-test scores.

Although these results are encouraging, the professor in this case still mainly utilized a lecture format for the course. The course also did not have a laboratory component, but instead, featured in-class demonstrations. It was not mentioned how often these demonstrations occurred. Though in-class demonstrations have been shown to be mostly ineffective in engaging and teaching students, there have been positively associated results when used in certain fashions. Laboratory components, where students play a greater role in demonstrations, have been shown to be even more effective at increasing student learning (Mackin, Cook-Smith, Illari, Marshall, & Sadler, 2012). Compared to Goldsmith's study, there may also be differences in results if this method were used at a larger school with greater class sizes. Thus, this format may be better than lecturing with the tradition curriculum, but it is not necessarily the best option.

In a 2012 study of a specific type of classroom demonstration, *Weather in a Tank*, classroom demonstrations were shown to increase student engagement and achievement in introductory atmospheric and oceanic sciences classes. After finding that classroom demonstrations did little to bridge the gap between concrete problems and abstract mathematical models, a group of Massachusetts Institute of Technology researchers created a series of in-class demonstrations centered about rotatable tanks of fluid. Used at 26 undergraduate institutions with over 700 students, these were shown to help students connect abstract concepts to the physical world, increasing their understanding of phenomena like hurricanes and weather fronts. Treating the demonstrations more as experiments, students were asked to make predictions using prior knowledge, help with experiments, make observations, discuss findings, question outcomes, make connections, and test mathematical models.

The effectiveness of these experiments was measured using qualitative data (student and instructor perceptions) and quantitative data (pre- and post-test scores). Students in the treatment groups had at least four classroom experiences involving *Weather in a Tank*, while several comparison groups had none. Both groups were tested in both introductory lecture-based courses and advanced lecture-based courses, but only treatment groups were tested in advanced laboratory-based courses. As a consequence of including introductory courses, the groups included science and non-science majors.

Instructors viewed student engagement during the experiments as having a positive effect on student understanding and ability to visualize concepts. They also perceived their classes as participating in richer discussion with heightened student interaction. Students felt that they were more interested in the course, understood more material, and were more motivated to apply abstract concepts and mathematical models to what they had learned. Pre- and post-test scores revealed that the demonstrations were most helpful for novice students in introductory courses and advanced students in laboratory-based courses (Mackin et al., 2012). This study is critical for illustrating that in-class experiments and demonstrations can advance student understanding and attach concepts firmly to a conceptual framework in the early stages of acquiring Geoscience knowledge. What appears to be key is that students must be active participants of the demonstration. They cannot merely exist as passive observers.

Models like *Weather in a Tank* are useful because they capitalize on natural human behavior- that we use analogies to take an up-close look at phenomena. In early education, students may use representations and models when they cannot touch or see the concept they are learning about. Models can cause students much confusion for many reasons such as being very large or very small scale or maintaining some characteristics of the phenomena they model while leaving out others (Michaels, Shouse, Schweingruber, & National Research Council, 2008). By definition, models are imperfect representations of the phenomena they represent. According to Sibley, “Scientific models are representations of natural phenomena accepted by a community of experts that share similarities with a target and allow one to make testable predictions or retrodictions about the target” (2009). The ability to make and understand models is an important aspect of science literacy, especially in the field of Geoscience. In this field, models are relational analogies. This means that the models reflect shared relationships with the target including processes and causation and are not limited to mimicking physical characteristics.

Understanding how students construct models can aid instructors in facilitating better model making in their classrooms. In a literature review focusing on modeling in Geoscience, Sibley explained how instructors could begin this process by presenting quality analogs to their students. Students would start by assessing the similarities and differences between the target and the model and then draw inferences about characteristics of the target based on the model. In an evaluation process, students would assess the quality of the model-target relationship. Moving from a concrete understanding to an abstract conceptualization, modeling leads to making generalizations (and abstractions) about the model or concept and finally, re-representing the model by making improvements or extending its applications. In this way, modeling has the ability to connect prior knowledge with knowledge in the process of being learned, and furthermore, it can branch forward, providing coherence to concepts later approached (2009).

Another challenging component of early undergraduate Earth Science pedagogy is that non-major classes tend to have very large student enrollments. In their 2009 study, Arthurs and Templeton attempted to over come the issues associated with large enrollment, such as physical layout of a lecture hall and logistics of working with numerous students, in order to design an environmental geology course based on a constructivist ideology. In a constructivist course model, students are active participants in the learning process and build their understanding of concepts based on their experiences. In this research study, five in-class activities with follow up homework assignments were conducted throughout a semester. The goal was to improve the students' attitudes toward science and learning science as well as to increase their content knowledge and understanding of environmental concepts.

These in-class activities varied in topic and difficulty to keep students engaged and motivated. Students worked in small groups to complete the activities which were designed to include relevant societal problems, require students to stay mentally present, and directly correlate to topics covered in class and applied in the homework. These topics included the rock cycle, subsurface water, Uranium mining, water quality and drinking water standards, and arsenic poisoning in Bangladesh. These concepts vary in their level of abstraction, but all are relevant geologically if not socially and economically.

The study found that although the students initially were divided about their desire to work in groups, by the end of the course most students surveyed said that the collaborative activities were helpful their learning process. Attitudes and post-course test scores both showed positive gains compared to pre-course attitudes and scores. The instructor also felt that the in-class activities exposed student misconceptions about abstract topics. Students held misconceptions even about the most basic abstract topic, the rock cycle.

It was suggested in this study that the course be structured with longer, but fewer, meeting times in the future to allow students to spend more time on activities. Students also requested more challenging problems with extra time spent on introduction of the activity and debriefing of the activity. These results are supported by multiple studies on large enrollment Earth Science and Physics classes, which found that active learning techniques, supported by reasonable assessment, enrich the student experience (Yuretich, Khan, Leckie, & Clement, 2001; Meltzer & Manivannan, 2002; McConnell, Steer, & Ownes, 2003). Because time is less limited in laboratory components and class sizes are relatively smaller compared to the lecture population, it is necessary to explore the laboratory as a different, but connected avenue for effective pedagogy.

2.4 Attempts at Effective Pedagogy in the Laboratory

In a comprehensive literature review on multiple aspects of secondary science laboratory components, Hoftein and Lunetta found that these special learning experiences do not simply deepen student understanding of processes, models, relationships, concepts, and materials (2004). When done effectively, they also illustrate for students how science is practiced and create opportunities for them to practice science within a community. Unfortunately, the inquiry-based activities that would benefit students the most are often viewed as too difficult or time consuming. Students are most often taught with less-than-best practices. They use cookbook manuals. Also, as practices and applications learned in laboratory are not accessed on most tests, students do not see laboratories as critical for learning. Often students confuse terms in the laboratory with terms used in a social context, and few instructors check to ensure all students working in the laboratory use the same definitions. The experience of being in the laboratory can easily overwhelm students, forcing them to reject or mediate how much new information they can fuse with prior knowledge (Johnstone, 1991). These practices, although a symptom of science laboratories as a whole, are also reflected in the Geoscience laboratory.

Instead of using activities in lecture to teach a Geoscience concept, Apedoe, Walker, and Reeves (2006) explored the effect of restructuring the laboratory component of an undergraduate Paleobiology course. Prior to the study, each lab was individually reconstructed to incorporate only the information the professor deemed most relevant, and each was formatted with a maximum amount of hands-on, experiential, and inquiry-based activities. Maximum content assimilation was not the singular guiding objective for the course. Rather, the goals were more closely aligned with developing a set of scientific process skills and increasing comprehension of valuable content. To accomplish these goals, students were presented with authentic problems concerning real data, like fossils and maps. After a period of adjustment to the uncommon design, students actively participated in collaborative efforts to construct new knowledge and performed well on inquiry-based assessments.

This period induced a feeling of uneasiness in both the instructor and the teaching assistant coordinating this laboratory session. The instructor felt that an over-abundance of samples caused the students anxiety and limited their discussion. They also felt that additional regional perspective was needed in the form of maps, and a variation in activity type and pace were necessities for future versions of this laboratory. The teaching assistant was unprepared to teach an inquiry-based laboratory session, which suggests that this form of engagement requires a time commitment for training purposes. Leaping away from the traditional method of teaching laboratory components of courses may discourage some instructors, and the unease associated with confused students and untrained teaching assistants may deter others.

Although the students performed well in this course, it should be noted that these students were geology majors and therefore, possessed additional motivation to perform as such. Topics covered in this class, like biostratigraphy, paleoecology, and taphonomy, are certainly abstract in their temporal component, and may have been more easily understood by students self-selecting into a science major. An existing Geoscience framework constructed in other Geoscience courses would also have supported the abstract processes associated with these topics. Thus, this method may prove less successful with secondary students and non-Earth Science majors who will require more guidance with lower level concepts.

A special aspect of Geoscience Education is that nature is itself a form of laboratory. Field experiences simply cannot be mimicked in a classroom environment.

Moreover, they can engage students and foster curiosity that can be carried over into studies in the classroom. At the University of Pittsburgh, a capstone course affords students the opportunity to design and lead their own field trip. During planning for this experience, students built upon their prior knowledge of geology, increased their communication skills by writing reports and preparing talks, and increased their motivation to learn as they took ownership over their own education. Students reported this method of learning required more effort, but that they gained additional understanding due to being immersed in the action of learning. Teachers in this scenario were facilitators, passing the majority of the responsibility for learning over to the students. Too often, field experiences are so teacher-centered that only the most self-motivated students learn (Todd & Goeke, 2012).

Comfort in the field also limits student learning during field experiences. Geoscience programs are now seeing more students classified as "urban thinkers" in their classrooms. Urban thinkers are less experienced at making detailed observations associated with Earth Science due to their minimal exposure to nature and increased exposure to the built world. This increase in urban thinkers is due to the migration of a large portion of the population to urban areas and increased exposure to digital media. Urban thinkers can often have less developed cognitive abilities like spatial skills, have a disinterest in nature, experience discomfort in nature, and fear being in nature. In response, mini-field trips around campuses have been encouraged as effective pedagogy in introducing urban thinkers to the forces that shape a landscape (d'Alessio, 2012). Although this method has been applied at the secondary and post-secondary levels, it cannot serve as a full replacement for traditional field studies.

Many laboratory courses use manuals that guide students through experiments to relieve pressure on teaching assistants. Buck, Bretz, and Towns (2008) evaluated 386 activities in twenty-two undergraduate level laboratory manuals based on the level of student independence allocated during the activities. Out of these, three manuals and forty-six activities were geology-related. Activities were assigned a level from zero to three, where zero corresponded to an activity in which all steps and answers were provided to the students ("confirmation") and three corresponded to an activity involving authentic inquiry. No geology manuals were found to provide a higher level of inquiry than confirmation, a title that affords no intellectual autonomy from the generation of a problem or question to the deduction of conclusions. Cookbook laboratory manuals like these provide students with little motivation and reward discrete, expected ends to experiments.

In the physics field, a constructivist laboratory design, emphasizing discussion, collaboration, and student-designed experiments, has been shown to result in more authentic learning at the secondary education level. Roth (1994) explored the various reasons students gain little from a rigid laboratory setting and whether they would develop into scientific thinkers in an inquiry-based laboratory in an all-male secondary school. Bored students tended to remain off task during designated laboratory time in traditional settings, causing the teacher to give a quickly paced lecture to ensure that important topics were covered. These forms of laboratory and lecture learning were linked to an objectivist perspective wherein students are passive learners and knowledge is poured into their brains via a more knowledgeable individual. In the inquiry-based physics laboratory, new knowledge was constructed both individually, in small groups, and in one large group. In this environment, each student formed his own representation or understanding of a topic and linked this understanding to the group knowledge.

The study focused on the development of student communication, strategies, data collection, and analysis with respect to authentically challenging problems that grew out of that knowledge. The student experience in the constructivist laboratory was mostly defined by performing experiments and writing laboratory reports. However, the students also read from their textbooks and other sources, created concept maps, worked textbook problems, wrote an essay, and participated in weekly whole class discussions. Students learned to frame appropriate research questions, a skill considered highly valuable in the problem solving process. A new understanding of the flexibility of the scientific method was gained once students realized unpromising hypotheses could be abandoned. They felt ownership and control over their learning experience, and remained engaged throughout the laboratory sessions. Unlike a traditional linear course pathway, this laboratory format did not lend itself to a sequenced presentation of topics. Instead no topic boundaries existed, allowing students to interweave strands of scientific concepts like velocity and density when needed during an experiment. This attributed to an overall coherence in the course content.

Geoscience, though, has varying challenges relative to physics. In a physics laboratory, laws and properties are innately experiential and containable in activities. This is clearly not the case with the abstract concepts of Earth Science. For example, while experiments concerning the physical properties of rocks (streak, density, color, and hardness) are certainly feasible, experiments which model the rock cycle would require expensive and sophisticated equipment. Analogous materials like wax could be used in place of rock and would easily model melting and crystalizing of rock, but they would not provide an understanding of time in the process of rock formation. Nevertheless, these inquiry-based laboratories provide a starting point for the possible design of an Earth Science course in which the focus is to make abstract topics more concrete.

2.5 Summary

It is well understood that students maintain conceptual issues in Geoscience even after years of supporting education both in the classroom and laboratory. In a 2010 literature review of 79 studies related to student conceptions in Earth Science, numerous misconceptions were identified (Cheek, 2010). Of these studies, at the secondary and college level, students had difficulties identifying rocks, drawing plate boundaries, using geologic terms correctly, and accurately visualizing the structure of the Earth. The hydrologic cycle was a source for confusion as well, as more than a fourth of undergraduates who participated in the study did not include groundwater in a depiction of this cycle. Plastic flow within the mantle was misconstrued as fluid flow, implying many of the students in one study believed the mantle to be molten. Overall, the largest issues concerned spatial and temporal scales of geologic events and processes. For example, some adults believed that the Earth formed at the same time as the Universe. Clearly, Geoscience researchers are capable of identifying misconceptions held by students, but of all the studies reported, only nine offered and tested means of intervening to correct these misconceptions.

Although students may bring with them misconceptions to a secondary or undergraduate Earth Science course, the studies discussed above illustrate how aspects of these misunderstandings can be corrected. They show how students *can* learn effectively despite large enrollments and other obstacles, but only if their instructors work to *teach* effectively. As inspiration points, the one or two methods each highlight apply to the laboratory or the classroom, but not both. After reviewing the literature, it is clear that Earth Science is missing an inclusive pedagogy- a set of strategies and curriculum for an introductory level course, which maximizes student engagement in the laboratory, classroom, field, and life. Students should be guided through effective practices like concept mapping, inquiry, and investigating case studies so that they can build on prior knowledge in a relevant and meaningful way.

For many schools, this venture may entail pairing down the topics covered, such that the remaining curriculum can be explored at depth. At the secondary level, this is suggested in conjunction with learning progressions in the Next Generation Science Standards (National Research Council, 2011), but at the college level, simply changing what is routine may prove difficult. It will require professors and teachers to obtain training with inquiry-based teaching methods and to work with students on a personal level to understand where they are in terms of concrete or abstract thinking. Working toward an inclusive pedagogy for Earth Science will necessitate exploration, creativity, passion, and change on the parts of many instructors, but it will be for more than encouraging informed citizenship of students. It will be for sharing a perspective, a perspective of our connection as humans to a globally and universally big picture.

CHAPTER 3. STUDY RESULTS

3.1 Results of Survey

The survey asked students to rank how much they agreed or disagreed with a given statement on a scale from one to five. The survey consisted of ten statements, which measured attitudes and beliefs about Geoscience. These were much inspired by the main tenets of the Earth Science Literacy Principles document (Earth Science Literacy Initiative, 2010) and are featured in Table 3.1 along with the average student agreement with that phrase on the first and last days of lab. The lab associated with enforcing each of the ESLPs is recorded in Appendix B. Because students withdrew from the course and because many students were absent the last day of lab, fewer students completed the second survey. Thirty-seven students participated on the first day, while only twenty-eight students participated on the last day. For this reason, an unpaired t-test was used. All phrase agreement increases were statistically significant except for the phrase that relates the students' current choices about the environment. Although changes in attitudes and beliefs have not been measured in previous years, observations of students and details from student responses about the course allow us to comfortably contribute these gains to the improved pedagogical practices employed during the course.

Table 3.1

Survey Results

Phrase	σ_i	μ_i	σ_f	μ_f	p-value
I am interested in learning about scientific concepts.	0.80	3.83	0.85	4.29	0.015
I make responsible choices concerning the environment.	0.89	3.64	0.72	3.68	0.419
I have an impact on the health of our planet.	1.13	3.69	0.83	4.36	0.005
Human activities significantly change the rates of many of Earth's surface processes.	0.85	3.94	0.50	4.61	0.00025
I know where to find accurate information about geoscience concepts.	1.03	3.00	0.69	4.04	0.00001
Geology affects the distribution and development of human populations.	0.86	3.75	0.49	4.64	0.000003
Human activities can contribute to the intensity and frequency of natural hazards.	0.80	4.03	0.69	4.39	0.030
I know enough about geoscience to make informed decisions in this area.	1.05	2.81	0.61	4.00	0.0000006
I would feel comfortable voting or discussion my opinions with others concerning a geoscience issue.	1.0	3.06	0.69	3.96	0.00005
Earth science education is important for everyone.	0.84	3.89	0.69	4.43	0.0038

*Subscripts of "i" indicate values associated with the initial survey. Subscripts of "f" indicate values associated with the final survey. Sigma (σ) represents the variance of the data, while mu (μ) represents the mean of the data.

3.2 Results of Exams

Table 3.2

Exam Results

Statistic	Exam 1	Exam 2
Mean	89.4	90.8
Median	91.8	93.9
Range	26-100	77-100

*Note that the range reported does not show a zero for a student who did not report to the second exam

The lab component of the course required the students to take two exams. We recognize that since the exams were not distributed prior to learning and after learning, and since they do not test similar concepts, they cannot technically be considered pre- and post- tests of the material. However, because the first test was taken toward the beginning of the semester and the second was taken as a final, the slightly improved grades may indicate familiarization with an active form of assessment. The means and medians for both exams are listed in Table 3.2. The mode for both exams was, surprisingly, a 100 percent. In the future, the use of true pre-tests and post-tests, such as those that can be created by the Geoscience Concept Inventory, will better gauge student cognitive gains.

3.3 Student Opinion/Course Evaluation

Student reviews were submitted via the Purdue course evaluation system, and many students completed comprehensive written reviews of the lab component. Common themes in student responses included that the lab and lecture components did not complement each other very well in the style in which they were taught, the methods of teaching and learning made the content being taught more accessible, and that the homework assignments were not reflective of material being taught in the lecture or the lab. Some such comments are listed in Table 3.3.

There were negative comments that related to the lab. These included that the lab was too long, the metacognitive activities were too juvenile, and there was not enough differentiation for advanced students; however the same student made the first two complaints. As far as differentiation issues are concerned, the course population had a select group of advanced students who completed the material timely and produced high quality work. These exceptionally motivated students did not accurately represent the course population as a whole.

Table 3.3

Examples of Student Responses to the Course Evaluation

The lab was 3 hours long. I feel this is too long for a 3 credit hour class. I would recommend cutting this to 2 hours instead.
The homework assignments were often very long and not entirely related to what we were studying at the time.
I think the course would be better if the lectures and labs were more integrated. I hope that the lab part of this class with stay working in groups and discussing as a group. I know this has been extremely more effective for learning than just copying material from a textbook and not discussing topics.
I liked being able to work in groups and creating posters during our labs.
i've found myself reading things and looking up things outside of class on this subject, simply because i've come to find it interesting and appealing as a hobby at the very least. it is not necessarily my strong subject, but i have recognized things we learned in class on the internet and in articles and am able to explain it to my friends and family.
The labs were always interactive and assisted in the learning process, allowing us to use the information we learned to complete the labs.

I really enjoyed the hands-on base of each of the labs. It really helped cement in my mind what we were talking about in lab.

3.4 Conclusions and Applications to Lecture Component

We believe that due to affective gains displayed (reflecting Earth Science literacy achievement), the potential for cognitive gains, and the positive remarks received concerning the lab component, that this method of teaching an introductory Earth Science laboratory is an effective one for increasing Earth Science Literacy in young adults. The active pedagogy employed during the lab was student-centered, project-based, and inquiry-based, and served to motivate students to not just learn, but to learn more effectively.

Because of the success of the lab component in the Fall 2013 semester, the lecture component is undergoing likewise modifications for the Spring 2014 semester. Previously, lectures were presented in the traditional objectivist style with students quietly receiving information via PowerPoint slides from the instructor. The lectures will be modified to incorporate active-learning techniques, promote collaboration among students, and support long term Earth Science Literacy. Important topics were drawn from each of the previous years' lectures and reformatted pedagogically to be better received by students. This process required far more work than the restructuring of the lab, as we understood time in the classroom was more limited, much content is covered within the course, and enrollment is not low. The restructured lecture still incorporates PowerPoint lecture slides, however, these slides are now filled more modestly with graphic organizers, pictures, highlighted vocabulary words, and discussion questions.

Students have the opportunity to vote on multiple-choice questions during lectures, and then discuss their responses and the responses of their peers. They use websites for in-class research and take virtual field trips to museums and field locations.

Combined, the lecture and lab components, once completely remodeled, will represent the forward movement of effective Earth Science education at the early undergraduate level. We will have not only recognized the problems associated with traditional lecture and lab combinations within this discipline, but acted to improve the quality of experience students receive.

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APPENDICES

Appendix A

EAPS 112 Lab Survey

Please remember that your participation in this survey is voluntary, and it in no way affects your grade in this course. You may choose to not participate at any time- even if you have already begun. Please circle the number that best corresponds to your level of agreement with each of the following statements:

	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
	1	2	3	4	5
I am interested in learning about scientific concepts.	1	2	3	4	5
I make responsible choices concerning the environment.	1	2	3	4	5
I have an impact on the health of our planet.	1	2	3	4	5
Human activities significantly change the rates of many of Earth's surface processes.	1	2	3	4	5
I know where to find accurate information about geoscience concepts.	1	2	3	4	5
Geology affects the distribution and development of human populations.	1	2	3	4	5
Human activities can contribute to the intensity and frequency of some natural hazards.	1	2	3	4	5
I know enough about geoscience to make informed decisions in this area.	1	2	3	4	5
I would feel comfortable voting or discussing my opinions with others concerning a geoscience issue.	1	2	3	4	5
Earth science education is important for everyone.	1	2	3	4	5

Appendix B

For each lab, the specific ESLPs addressed in the material were recorded. This data are available as well for subcategories of each ESLP, but are not listed in this work due to space and size of data.

Lab	ESLPs Reinforced by Lab Material
1	1, 3, 8
2	1, 2, 3, 4, 5, 8
3	1, 2, 3, 4, 5, 6, 7
4	1, 2, 3, 4
5	1, 2, 4, 5, 6, 7
6	2, 5, 6
7	2, 3, 4, 5, 6
9	2, 3, 4, 6
10	1, 2, 3, 5, 6
11	1, 2, 3, 4, 5, 6, 7
12	2, 7, 8, 9

VITA

VITA

Education
B.S., Geology and Mathematics, 2012, University of Tennessee, Knoxville, TN
GPA: 3.79/4.0
Thesis: Shape and Thermal Modeling of a Selection of M-Type Asteroids
(*Faculty Advisor: Dr. Joshua Emery*)

Honors and Awards
Mayo Research Scholarship Recipient, 2011, University of Tennessee
NAGT Scholarship Recipient, 2011, National Association of Geoscience Teachers
KGMS Scholarship Recipient, 2011, Knoxville Gen and Mineral Society
Outstanding Senior in Geology, 2012, University of Tennessee
Dworkin Award Winner, 2012, Lunar and Planetary Science Institute
Ross Fellowship Recipient, 2012, Purdue University
Terry West Fellowship Recipient, 2013, Purdue University
Teaching Assistant Honor Roll, 2014, Purdue University

Association Memberships
Graduate Student Association of Earth, Atmospheric, and Planetary Sciences
Women in Science Program of Earth, Atmospheric, and Planetary Sciences
Pi Mu Epsilon Alumni (Math Honors Society)
National Association of Teachers of Mathematics
Association of Engineering Geologists, Northeast Division

Teaching Experience
Teaching Assistant, Spring 2012, University of Tennessee
Teaching Assistant, Fall 2013, Purdue University
Course Assistant, Spring 2014, Purdue University
Student Teaching, Spring 2014, Jefferson High School

Professional Presentations
Shape and Thermal Modeling of a Selection of M-Type Asteroids
Lunar and Planetary Science Conference, 2012

Preliminary Analysis of Causes of Subsidence in Association with Abandoned Coal Mines, Southwestern, IN
Association of Engineering Geologists, Northeast Division, 2013
Indiana Academy of Science Meeting, 2013

Coal Mine Subsidence in Southwestern, IN
Indiana Society of Mining and Reclamation Conference, 2012

Thermal Inertia of a Metallic Regolith: A Simulant Sample Experiment
Lunar and Planetary Science Conference, 2013

Publications and Papers

Emery, J.P., Fernandez, Y.R., Kelley, M.S.P., Warden, K.T., Hergenrother, C., Lauretta, D.S., Drake, M.J., Campins, H. Ziffer, J. (2014). *Thermal Infrared Observations and Thermophysical Characterization of OSIRIS-REx Target Asteroid (101955) Bennu.* Submitted to Icarus

Crane, K.T., West, T.R. (2013). *Prioritizing Grouting Operations for Abandoned Underground Coal Mines, Southwestern, Indiana*
Submitted to Environmental and Engineering Geology