

ABSTRACT

CZAJKA, CHARLES DOUG. Two Case Studies in Reforming Undergraduate Geoscience Education: Instructional Change in a Lecture Class and Increasing Inquiry in a Geologic Time Lab. (Under the direction of Dr. David McConnell).

Progress towards reforming undergraduate STEM education has been less than ideal despite 20+ years of empirical evidence demonstrating the efficacy of reformed teaching practices in promoting positive student outcomes. The case studies presented here investigated two methods for reforming undergraduate geoscience education that can aid in overcoming common barriers to reform.

Commercially available geology lab manuals tend to engage students at a very low level of scientific inquiry and may not promote student learning of difficult concepts. Research shows that students hold many misconceptions regarding the timing and scale of events in Earth's history. In the first case study, the inquiry level of the Earth history portion of a geologic time lab was increased from a mostly confirmation level to a mix of structured and guided inquiry. It was found that students in the revised higher inquiry geologic time lab performed significantly better on the end of course assessment than those in the original lab. Revising lab experiences to enhance student understanding of concepts as evidenced by performance on assessments does not have to involve time-consuming overhauls of lab activities. Carefully crafted revisions to lab activities that result in higher inquiry can increase student performance on related assessments.

Barriers to reforming traditional lecture-based undergraduate STEM classes are numerous as evidenced by the less than ideal adoption rates of reformed teaching strategies among college faculty. These barriers include time required to revise courses, lack of training in the use of reformed teaching strategies, and instructors' own beliefs about teaching and learning. The second case study documents the piloting of a new collaborative model for promoting instructional change, titled situated instructional coaching. Under this model, a geoscience education graduate student (the coach) assisted a faculty member seeking to reform an introductory geoscience course. Every lesson for the course was rewritten with new learning objectives, student activities, feedback, and assessments. The revision process occurred in three phases, which shifted the responsibility of lesson design from the coach to

the instructor by the end of course. Data on instructional practices was collected using the Reformed Teaching Observational Protocol (RTOP) and belief changes experienced by the instructor were captured using the Teacher Beliefs Interview (TBI) and Beliefs about Reformed Science Teaching and Learning (BARSTL) survey. RTOP data confirm that the instructor was able to successfully teach the reformed lessons as designed and also gained skills in designing reformed lessons. TBI and BARSTL data indicated a shift in the instructor's beliefs toward a more student-centered perspective. Situated instructional coaching presents an alternative to the more traditional dissemination methods of reformed teaching such as papers, talks, workshops, and seminars.

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Two Case Studies in Reforming Undergraduate Geoscience Education: Instructional Change
in Lecture Class and Increasing Inquiry in a Geologic Time Lab

by
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BIOGRAPHY

Doug received his B.S. in Geology with a historical concentration from NCSU in 2002. In 2003 he began working with the NC Department of Transportation as an engineering geologist. At DOT he spent most of his time preparing reports on subsurface geology for road and bridge foundations. In the spring of 2011 he decided it was time for a change so he left his job at DOT and spent the summer in Thailand training Muay Thai. Upon coming back to NC, Doug returned to NCSU in the spring of 2012 to pursue a Master of Arts in teaching. After sharing a class with Laura Lukes and talking about her research in discipline based education, he decided to transfer into the Geology department and join the Geoscience Learning Process Research group.

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CHAPTER 1: INTRODUCTION

The President's Council of Advisors on Science and Technology's (PCAST) report expresses concern that we are losing too many science, technology, engineering, and mathematics (STEM) students along their academic journey (PCAST, 2012). Fewer than 40% of students entering college as STEM majors complete a STEM degree (PCAST, 2012). The result of such losses could be a STEM workforce shortage in the near future if an additional 1 million STEM graduates are not produced in the next decade (PCAST, 2012). The PCAST report's number one recommendation for meeting this goal is to "catalyze widespread adoption of empirically validated teaching practices." The recognition that students leave STEM majors in significant numbers is not new (Seymour and Hewitt, 1997). Neither is the call to change how introductory STEM courses are taught (NRC, 1999; Handelsman et al., 2004). Research continues to report that programs which successfully retain STEM students feature evidence-based instruction in introductory courses (Graham et al., 2013).

These recommendations and reform initiatives call for the adoption of empirically validated instructional practices known by an array of names such as student-centered teaching, active learning, research-based instructional practices, or reformed teaching (NRC, 1999; Handelsman et al., 2004; PCAST, 2012). These techniques have been shown to promote student learning and performance on assessments (Crouch and Mazur, 2001; Kortz et al., 2008). The research outlined herein reports on the findings from two case studies looking at different methods of reforming undergraduate geoscience education. The first case (Chapter 2) examines the impact that increasing the inquiry level of a geologic time lab has on student performance on assessments related to the timing and scale of key events in Earth's history. The second case (Chapter 3) describes the piloting of a collaborative professional development model, dubbed situated instructional coaching, for promoting change in instructional beliefs and practice in an introductory geoscience course. Data were collected to assess the impact that implementing reformed teaching strategies through situated instructional coaching would have on an instructor's practice, lesson designs, and their beliefs about teaching and learning.

CHAPTER 2: INCREASING INQUIRY IN A GEOLOGIC TIME LAB

2.1 Background

Many undergraduate students are required to take a science course with a lab as part of their degree curriculum. The purpose of this lab course, from the student and instructor perspective, is often not clear or well understood (Russell and Weaver, 2008). While lab courses can and should serve as a venue to reinforce concepts learned in the lecture portion of a course, they should also serve as a place for students to gain hands-on experience with the processes of science and the nature of scientific inquiry. It is often advocated that students gain these types of skills through inquiry-based learning (AAAS, 1991; NRC, 2000), which the NRC's National Science Education Standards define as:

“...a multifaceted activity that involves making observations; posing questions; examining...what is already know; planning investigations;...using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results.” (NRC, 1996 p.23)

Inquiry-based learning can be viewed as students learning science through personal involvement in the processes of science. This is in contrast to ‘cookbook’ lab activities/experiments in which students follow a prescribed set of steps and protocols to arrive at known conclusions. The National Research Council (NRC, 1999) called for fundamental changes in STEM education at the undergraduate level to provide more opportunities for students to study STEM as it is practiced. The NRC advocates that all undergraduates should experience at least one laboratory course in which they can be involved in the active learning of science through scientific inquiry and not simply “following rote procedures to address predetermined questions and to arrive at conclusions that are widely known...” (NRC, 1999).

Research on inquiry-based (IB) learning within the laboratory environment has investigated many factors ranging from students’ attitudes and learning gains to the teaching assistant (TA) experience and TA-student interactions. Students within IB labs find them more exciting than traditional labs (Basey et al., 2008), demonstrate more frequent inquiry

behaviors (observing, analyzing, predicting, etc.) and are involved in more in-depth student-student discussions (Cianciolo et al., 2006; Xu and Talanquer, 2013) than students in non IB labs. Students in IB labs also show improvements in science literacy and process skills (Brickman et al., 2009; Derting and Ebert-May, 2010; Treacy et al., 2011). Research looking at inquiry and students' confidence in performing and applying science skills has yielded mixed results. Students in traditional labs reported significantly greater gains in self-efficacy from pre- to post-course than those in IB labs (Brickman et al., 2009). Elsewhere, students in IB labs showed significantly greater gains in self-confidence in addition to more positive attitudes toward science and research (Brownell and Kloser, 2011).

The implementation of IB labs not only enhances students' scientific literacy and lab experience, but can also promote increased learning and performance on assessments (Luckie et al., 2012). The NRC called for continual and systematic evaluation of STEM courses, stating "faculty would continually evaluate their courses for efficacy in promoting student learning" (NRC, 1999). Discipline-based education researchers are beginning to look into the effect that IB labs have on student learning and performance. Revising individual 'cookbook' labs in biology courses to incorporate more inquiry has been shown to improve student performance on summative assessments. For example, students in sections of an introductory biology lab that utilized cooperative learning and experimental design did better on weekly quizzes than those the more traditional labs (Lord and Orkwiszewski, 2006). Additionally, students who participated in a revised lab on enzymes that incorporated more student observation and experimental decisions did better on post lab assessment questions than students in the original labs (Rissing and Cogan, 2009). Rissing and Cogan (2009) suggest that the persistence of traditional labs in biology is driven by the need to cover content students need in order to be successful on graduate and professional tests, such as the Medical College Admissions Test (MCAT). However, later studies have shown that students in 7 and 14 week long inquiry lab sequences outperformed students taking a traditional series of 1 week labs on the MCAT (Luckie et al., 2012) as well as on informal assessments (O'Sullivan, 2012).

Research on IB labs in other STEM disciplines has been less extensive than in biology, and has produced mixed results. One study looked at the inclusion of guided inquiry in physics labs, which the authors define as “a lab that does not have a[sic] specific questions or written procedural directions for the student to follow.” The results showed no significant improvement on knowledge-specific assessments between students in the traditional labs and those in the guided inquiry labs (Nelson, 2012). A study in chemistry looked at the use of fewer labs using an argument-driven inquiry model, defined as incorporating student developed questions, methods, data, and reflections. Students in the argument-driven inquiry labs performed equally on concept knowledge assessments as those in traditional labs but developed more positive attitudes toward science (Walker, 2011). A study across five universities looked at the adoption of rotating tank experiments in atmospheric science and climatology courses (Mackin et al., 2012). These labs incorporated various inquiry activities such as student predictions, questions, and experimental design. The students who participated in the rotating tank labs outperformed students in more traditional labs on content knowledge post-tests. In an example from Earth science, the effect of inquiry-based learning on student conceptions of coastal eutrophication was investigated in an introductory physical geology lab course (McNeal et al., 2008). Students in the inquiry-based lab that made hypotheses, observations, and conclusions showed significant pre-post gains on conceptual model drawings and performed better on lab reports and drawings than students in a traditional workbook style lab.

Inconsistencies among researchers on inquiry in labs include the use of different definitions of what constitutes inquiry, different classifications of levels of inquiry, or even the failure to define what is meant by an inquiry-based lab. In an effort to alleviate this problem, Buck et al. (2008) created a rubric for evaluating the inquiry level of lab activities found in lab manuals across multiple disciplines. Their goal was to create a rubric that would remove much of the ambiguity found in previous classification schemes and be useful at a post-secondary undergraduate level. Their rubric (Figure 2.1) defines five levels of inquiry that range from confirmation to authentic inquiry. The inquiry level is based on six characteristics: a) problem/question; b) theory/background; c) procedure/design; d) results

analysis; e) results communication; and f) conclusions. These characteristics were drawn from elements found in laboratory manuals and experiments and are common aspects of scientific investigations (Buck et al., 2008). The inquiry level of an experiment or activity is determined by how many of the characteristics are student driven versus how many are provided by the lab manual. Confirmation activities are commonly referred to as ‘cookbook’ lab exercises, where students are provided with background information and then follow a set of procedures to arrive at a known conclusion or experience a new phenomenon. If a lab manual states that the mineral pyrite has a brownish-black streak and a student then carries out a streak test on pyrite, this would be an example of a confirmation activity. Having students determine the texture, silica content, and name of an unknown igneous rock sample would be structured inquiry. Using volcanic, seismic, topographic and geochronologic maps to infer tectonic boundaries would be an example of a guided inquiry exercise. Students using an earthquake machine to design an experiment and test hypotheses on the recurrence intervals of earthquakes (Hall-Wallace, 1998) would be an example of an open inquiry activity. Authentic inquiry is where students are involved in every step of the scientific process from asking their own research question all the way through to drawing their own conclusions; authentic inquiry is the closest to genuine scientific research.

A rubric to characterize inquiry in the undergraduate laboratory.

Characteristic	Level 0: Confirmation	Level ½: Structured inquiry	Level 1: Guided inquiry	Level 2: Open inquiry	Level 3: Authentic inquiry
Problem/Question	Provided	Provided	Provided	Provided	Not provided
Theory/Background	Provided	Provided	Provided	Provided	Not provided
Procedures/Design	Provided	Provided	Provided	Not provided	Not provided
Results analysis	Provided	Provided	Not provided	Not provided	Not provided
Results communication	Provided	Not provided	Not provided	Not provided	Not provided
Conclusions	Provided	Not provided	Not provided	Not provided	Not provided

Figure 2.1 Inquiry rubric from Buck et al. (2008).

Buck et al. (2008) used their inquiry rubric to analyze 386 experiments from 22 college laboratory manuals across 7 subjects. Each experiment represented a complete lab from a manual, and was given an overall inquiry rating. Only five experiments were rated as guided inquiry, with a majority (n=355) ranking as confirmation or structured (Buck et al., 2008). The geology manuals that they evaluated were among the lowest in terms of inquiry levels. They evaluated 46 experiments from 3 different geology lab books and rated them all as confirmation, the lowest level of inquiry.

The Geology I Laboratory manual at North Carolina State University (NCSU) was rewritten in 2009 and the inquiry levels of each lab activity or experiment were later assessed using the Buck et al rubric. Each lab is 2 hours and 45 minutes long and usually contains multiple activities on the day's topic. After the inquiry level of an activity was determined, the point value of the activity is divided by the total points available for the lab to arrive at an inquiry proportion. For example, a lab worth 50 points with a 20 point structured inquiry activity and a 30 point guided inquiry activity would be classified as 40% structured and 60% guided. Figure 2.2 shows the proportion of inquiry levels present in each of the 11 Physical Geology labs at NCSU for the academic year 2012-2013. No labs contain authentic inquiry so this level is not represented in the figure.

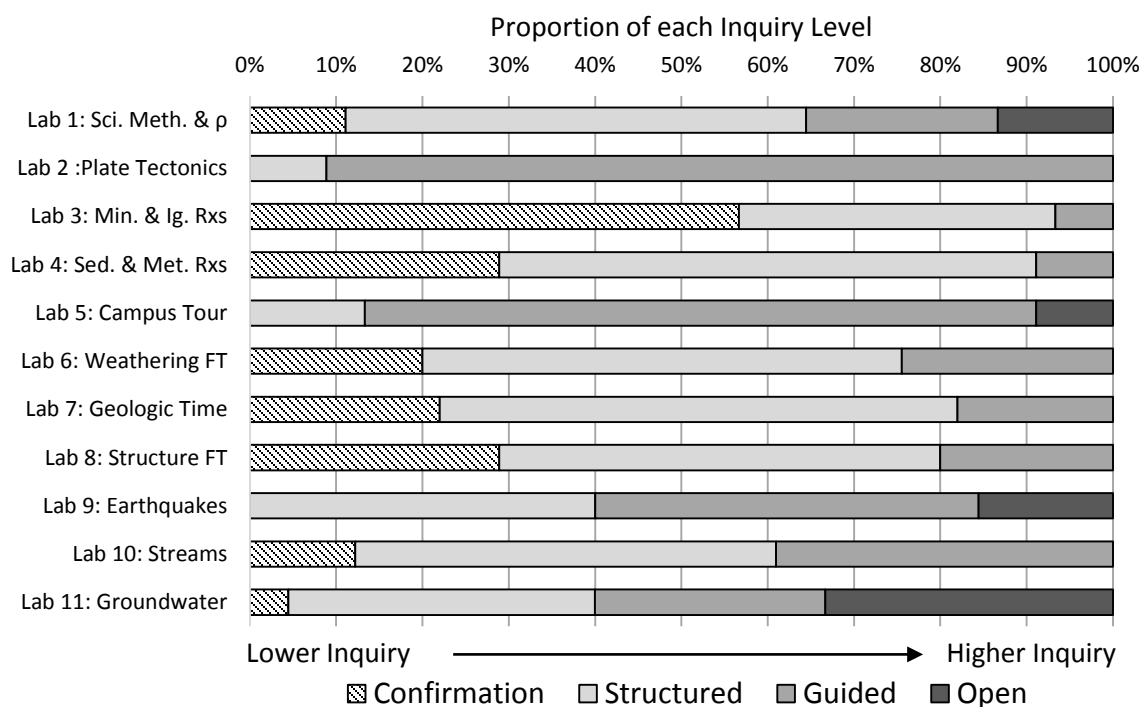


Figure 2.2 Proportion of inquiry levels in all Geology I: Physical labs at NCSU (K. Ryker, pers. comm.)

With the exception of the rock and mineral labs (Labs 3 & 4), the geologic time lab (Lab 7) has the highest proportion of the lower inquiry levels (confirmation and structured) in comparison with other labs. The geologic time lab was chosen as the focus of this research. The lab is divided into three components - Earth history, relative dating, and absolute dating, - with the Earth history portion of the lab taught almost entirely at the confirmation level of inquiry.

A review of the literature provides evidence that geologic time and Earth history are difficult concepts for many students. The concept of geologic time, or deep time, is one that is not only problematic for geoscience students of all ages, but also for many pre-service teachers (Trend, 1998; Dodick and Orion, 2003; Libarkin et al., 2007; Teed and Slattery, 2011). The ability to think beyond human time scales and into deeper time is fundamental to understanding important geologic concepts like plate tectonics, the rock cycle (Kortz and Murray, 2009), and weathering. This ability is not limited in its relevance to geology;

students who cannot grasp large time scales may struggle with concepts in other disciplines such as evolution (Dodick, 2007; Catley and Novick, 2009) or climate change (Lombardi and Sinatra, 2010).

While students have an adequate understanding of the order of key events in Earth's history, most struggle with the timing and temporal duration of events (Libarkin et al., 2007; Cheek, 2013). Students often underestimate the length of time between the origin of life and Phanerozoic events while exaggerating the time between events within the Phanerozoic. These distortions display a naïve conception of Earth's history and the temporal duration of events in geologic time. Suggestions for instructional strategies to improve students' understanding of geologic time and events include moving geologic time forward in geoscience curriculum to increase integration throughout course topics (Libarkin et al., 2007), creating collective landmarks to help students navigate through geologic time (Delgado, 2013), or using multiple well-constructed analogies (Jee et al., 2010). The use of analogies is common in the teaching of geologic time, comparing Earth's vast 4.6 billion year history to that of a single calendar year or placing it onto the length of a football field. However, as Cervato & Frodeman (2012) recently pointed out, little research has been done on the efficacy of such analogic thinking used in the teaching of geologic time.

The original Earth history portion of the geologic time lab at NCSU is taught largely using one central analogic activity. Students start out by reading about the geologic time scale and then as a class (maximum $n=20$) they place geologic events along a 46' foot tape measure to represent Earth's 4.6 billion year history. During the activity, each student is given a slip of paper with an event and its age in millions of years ago. The student then converts the age of their event to feet and inches and physically places the slip of paper at the appropriate location along the 46 foot tape measure located in the hallway. Students then do a smaller football field analogy where they calculate the yard line distance of the end-Permian extinction. Because the lab manual lists all the geologic time periods and major events that students place on the 46 foot timeline, these activities are classified as confirmation, the lowest level of inquiry. The confirmation inquiry level of this activity gave rise to the research question guiding this case: What effect will the inquiry level of Earth history

analogic activities have on student learning of geologic time as evidenced by student performance on assessments related to the timing and scale of key events in Earth's history?

2.2 Methods

In the spring of 2013, revisions were made to the Earth history portion of the geologic time lab in order to increase the inquiry level from confirmation toward more guided inquiry as defined by Buck et al. (2008; Figure 2.1). The principle revisions included omitting student readings, upgrading the timeline activity, and rewriting the pre-lab activity. In the original version of the lab, students completed reading from the lab manual about the geologic time periods and associated events. The 46 foot timeline activity was kept, but in the revised version students were given either a picture (such as a paleomap) or a fossil and were asked to predict the timing of their event (e.g., first appearance for fossils) by placing it along the tape measure. Working as a class with no prior instruction, students constructed an initial scaled timeline that represented 20 key events of Earth's history based on their predictions. Students were encouraged to work together and discuss their timeline predictions to refine their timings and the relative placement of events. After the students were satisfied with their timeline, the lab TA provided each student with the correct geologic age of their event. Students then calculated the correct placement of their event and moved their item to the correct location along the tape measure to create a now accurate timeline. The addition of the prediction component not only raised the inquiry level of the activity, but potentially makes the timeline analogy a more effective demonstration for students because making predictions before demonstrations enhances student learning (Crouch et al., 2004). Finally, students work together to identify two boundaries on the timeline and justify their placement, i.e. what is different on each side of their boundaries. New questions were also written to facilitate student-driven analysis and communication of the results from the timeline activity. Questions prompted students to analyze the fossil distribution along their tape measure and draw conclusions about their observations based on comparison to the actual geologic time scale. Table 2.1 compares the point value and inquiry level of each activity in the original and revised labs. Both labs can be viewed in Appendix A & B respectively.

Table 2.1 List of activities in the original and revised geologic time labs with associated point values and inquiry level. The entire original and revised labs can be seen in Appendix A & B.

Original Lab			Revised Lab		
Activity	Pts.	Inquiry Level	Activity	Pts.	Inquiry Level
Geologic Time Scale Metaphor Math	1	Structured	Timeline Equations & Predictions	5	Structured
Participation in Timeline	5	Confirmation	Boundary Creation & Timeline Analysis	6	Guided
Identify Research Question from Article	2	Structured	Geologic Timescale Demarcations	1	Structured
Identify Observations & Conclusions	4	Confirmation			
Relative Dating of Stratigraphy	8	Structured	Relative Dating of Stratigraphy	8	Structured
Creating a Stratigraphic Cross Section	6	Guided	Creating a Stratigraphic Cross Section	6	Guided
Paper Tearing Half-Life Demonstration	1	Confirmation	Paper Tearing Half-Life Demonstration	1	Confirmation
Half-Life Table, Graph, & Questions	12	Structured	Half-Life Table, Graph, & Questions	12	Structured
Half-Life and Ages of NC Rocks	2	Guided	Half-Life and Ages of NC Rocks	2	Guided
	41			41	

The pre-class activity for the geologic time lab was also rewritten. In the original form, students are given a blank space with two events from Earth's history listed in relative order. They were asked to fill in the space above and below the listed events with other events that occurred relative to these two. This activity was rarely effective with many students giving poor responses or providing only one or two events. In the revised version, students watch a short video from the Earth Science Literacy Initiative (www.earthscienceliteracy.org) on geologic time and then complete a temporal analogy where they calculate the appearance of *H. sapiens* if the Earth's 4.6 Ga history was compressed into a single 24 hour day. This activity seeks to improve student analogic thinking (Jee et al., 2010) and serves the purpose of scaffolding students up to the larger

spatial analogy in class. The pre-lab activity includes a question asking students to brainstorm gradual or catastrophic processes that shape the Earth over geologic time.

The proportions of each inquiry level in the new lab were evaluated using the same method discussed in section 2.1 (p.6) with the Buck et al. (2008) rubric (Figure 2.1) and compared to the original version (Figure 2.3). The revisions reduced the amount of confirmation in the geologic time lab from 22% to just 4% while increasing guided inquiry from 18% to 33%. The proportion of structured inquiry remained relatively unchanged, moving from 60% in the original lab to 62% in the revised lab. This shift from confirmation to guided inquiry occurred solely in the Earth history portion of the lab, as the relative and absolute dating portions of the lab were unchanged. Neither the original nor revised lab contains any open or authentic inquiry.

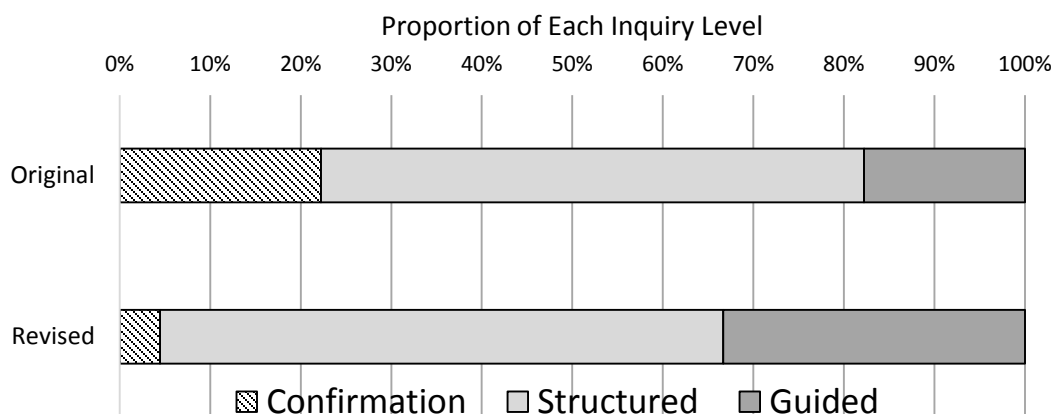


Figure 2.3 Proportion of inquiry in the original and revised geologic time labs.

Students were previously assessed on their knowledge of geologic time via two questions on the lab final exam. The final exam is worth 200 of the 900 points associated with the course and these two questions accounted for 9 points on the exam. The first question asked students which geologic time period of four choices was longest and the second asked them to place dinosaur extinction, first land plants, and first birds in the correct relative order. These questions assessed students at the lower levels of Bloom's taxonomy

(Bloom et al., 1956), knowledge and comprehension respectively. They therefore did not provide much insight into students' conceptions of Earth's history. In order to better assess the efficacy of the lab changes on student understanding of geologic time, a new assessment question was created for the final exam. The new question (Figure 2.4) provides students with a 4.6 inch line to represent Earth's 4.6 Ga history. Students are asked to plot labeled tick marks on the line to represent the origin of life, first organisms with hard parts, dinosaur appearance, non-avian dinosaur extinction, and the appearance of humans. The new question assesses students at the application level of Bloom's taxonomy by having them apply what they know about geologic time and Earth's history to a new analogy. The question is graded out of nine points and the grading rubric is provided in figure 2.4. To ensure content validity of the question, it was administered to the students and instructor of a graduate level class (n=8) on evolutionary transitions and minor changes to the wording were made based on input received.

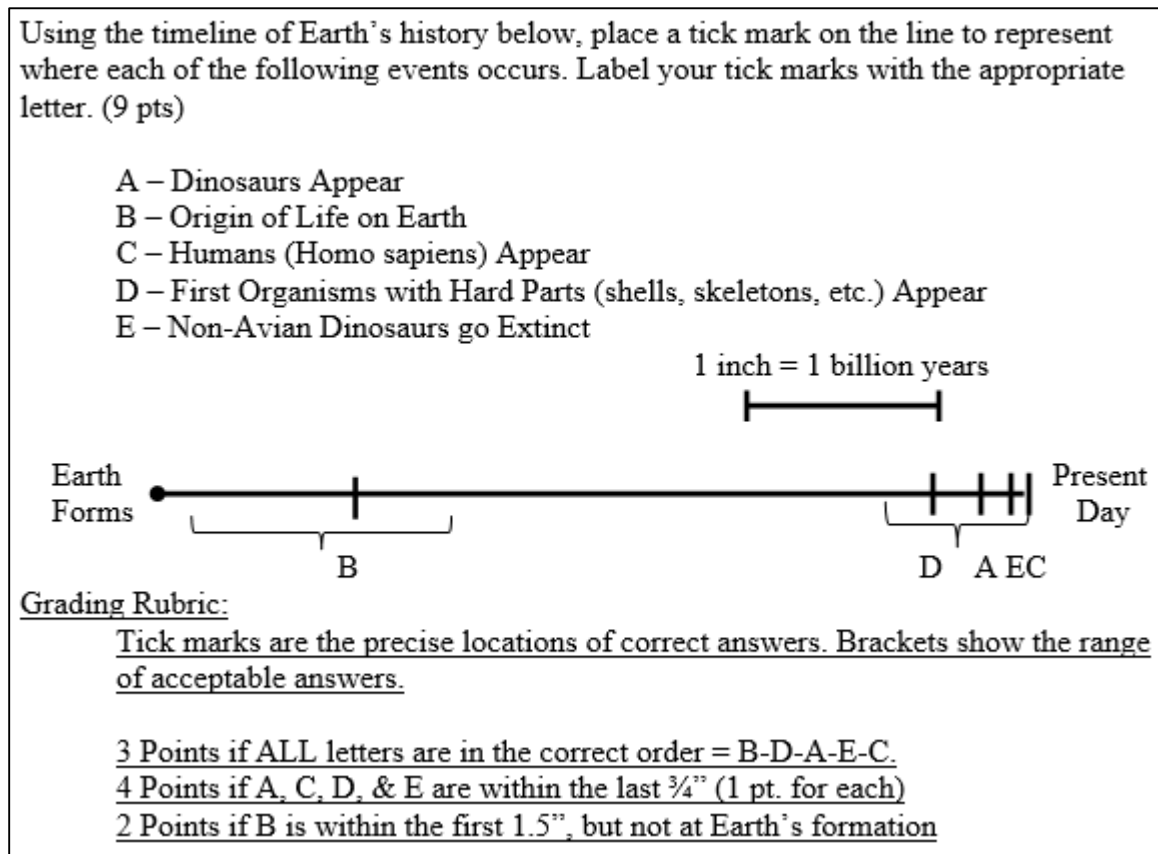


Figure 2.4 Lab final exam question on Earth history. Grading criteria is underlined.

Research data were collected during the spring (S13) and fall (F13) semesters of 2013 in MEA 110: Geology I Laboratory. The S13 semester had thirteen lab sections that participated, with six sections (n=86) serving as a control group using the original lab and seven sections (n=99) as a treatment group using the revised lab. The F13 semester had thirteen original sections (n=186) and eleven revised sections (n=153). TA's were randomly assigned to control or treatment groups each semester; some TA's who taught two sections in one semester used both versions, original and revised, while others taught two sections of the same version. All students completed the same lab final exam with the new geologic time assessment question. To measure students' prior knowledge at the start of each semester, all students completed a seven question geologic time multiple choice pre-test (expanded to eight questions in the F13 semester). The test was composed of questions from the

Geoscience Concept Inventory (Libarkin and Anderson, 2005) and a validated geologic time concept test (Rhajiak, 2009). The test consisted of four questions on Earth history, three on absolute dating, and one on relative dating (Appendix C).

2.3 Statistical Methods

Quantitative data from the pre-test results and scores on the final exam question were analyzed using IBM Statistical Package for the Social Sciences (SPSS). Independent t-tests were used for S13 and F13 individually to compare pre-test and final exam question scores of students in the original lab versus students in the revised lab. While a sample of convenience was used in the study, the assumption of normal distribution is satisfied based on the large sample size. The assumption of equal variances for both semesters were satisfied by Levene's tests for the pre-test ($p = 0.105$) and the final exam question ($p = 0.219$).

2.4 Results

Independent t-tests of mean scores on the pre-test showed no significant difference in prior knowledge between the students in the original lab versus those in the revised lab sections (Table 2.2). An additional Earth history question was added to the pre-test before administration in F13, making it out of eight points as opposed to seven. This explains the slightly higher mean on the pre-test for students in the F13 semester, but the mean expressed as a percentage of total score is consistent between sections (Table 2.2).

Table 2.2 Geologic time pre-test results

	Spring 2013					Fall 2013				
	n	Mean	%	σ	Sig. (2-tailed)	n	Mean	%	σ	Sig. (2-tailed)
Original Lab	71	3.10*	44.3%	1.49	$p = 0.219$	185	3.78*	47.3%	1.35	$p = 0.720$
Revised Lab	93	3.39*	48.4%	1.47		152	3.83*	47.9%	1.21	
		* out of 7 points					* out of 8 points			

Independent t-tests of mean scores for the Earth history question on the final exam showed that students in the revised higher inquiry lab scored significantly higher in both S13

($p = 0.001$) and F13 ($p = 0.000$) than those in the original lab (Table 2.3). Figures 2.5 & 2.6 show the proportion of students earning each score from 0 to 9 on the question for the S13 and F13 semesters. Students who score a 0, 1, or 2 on the final exam question struggle with the timing and order of most or all of the events. In the S13 semester, 16.3% of students in the original lab scored a 0, 1, or 2. In contrast, only 2.0% of S13 revised lab students scored this low. Scores of 8 or 9 were achieved by 23.8% (18.2% in S13 and 27.5% in F13) of students in the revised labs as opposed to only 12.1% (12.8% in S13 and 11.8% in F13) of students in the original lab.

Table 2.3 Student scores on lab final exam Earth history question (out of 9 points).

	Spring 2013					Fall 2013				
	n	Mean	%	σ	Sig. (2-tailed)	n	Mean	%	σ	Sig. (2-tailed)
Original Lab	86	5.10	56.7%	2.26	$p = 0.001$	186	6.07	67.4%	1.27	$p = 0.000$
Revised Lab	99	6.14	68.2%	1.71		153	6.68	74.2%	1.37	

Proportion of Each Score on Final Exam Question in S13

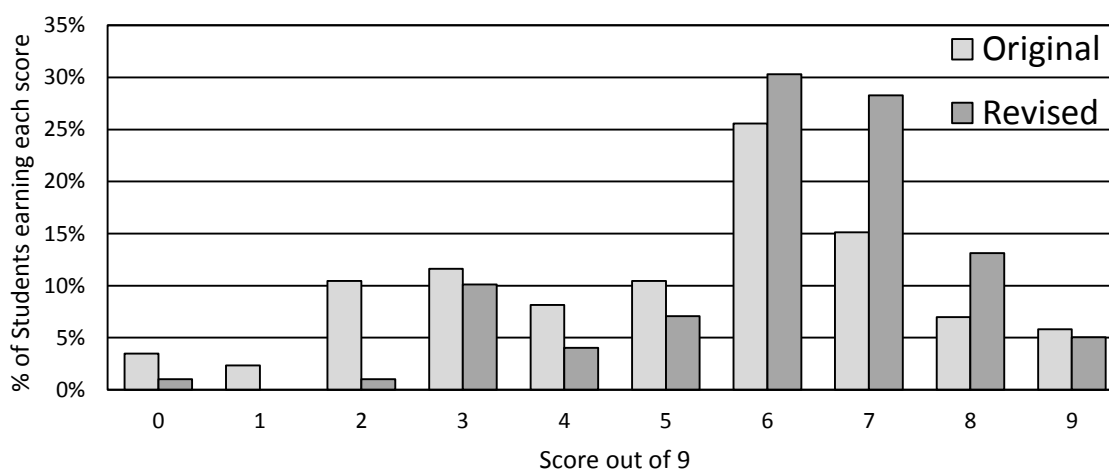


Figure 2.5 Spring 2013 (S13) student scores on lab final exam Earth history question for original and revised lab sections.

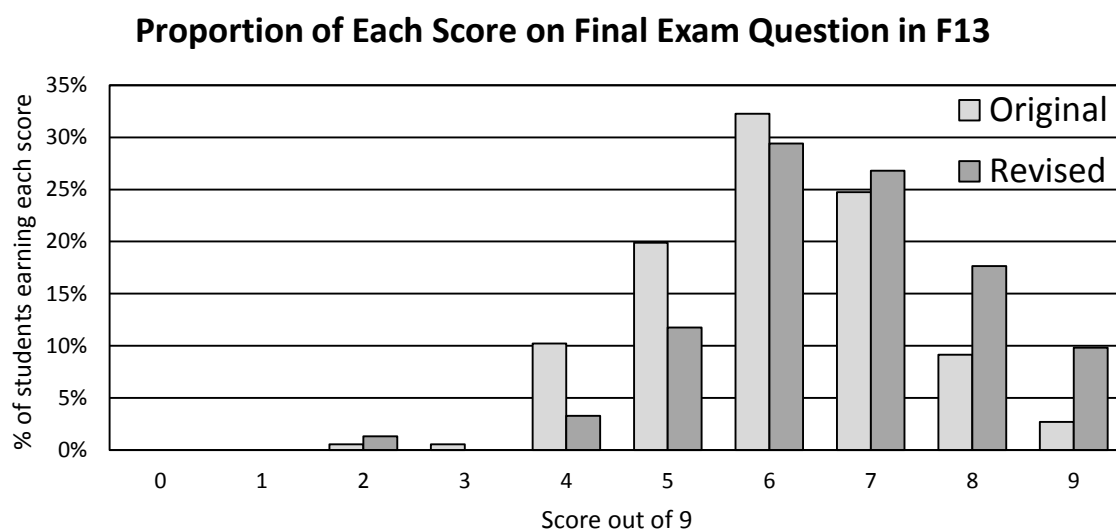


Figure 2.6 Fall 2013 (F13) student scores on lab final exam Earth history question for original and revised sections.

2.5 Discussion

Averages for both the original and revised sections were greater in F13 than in S13. Additionally, while students in the revised sections during F13 did significantly better than those in the original sections, the difference in average score was not as great as in S13. One possible explanation for these results is that between the S13 and F13 semesters there was a turnover of instructors within the associated lecture class, MEA 101, Geology 1: Physical. This change resulted in 57% of F13 students having lecture instructors with a student-centered instructional style versus just 27% in S13. The increase in scores from S13 to F13 may be a reflection of improved instruction on geologic time in the lecture portion of the course. This may also explain the near absence of students in F13 who scored in the 0-3 range.

Regardless of a student's experience in the lecture portion of a class, the revised higher inquiry version of the geologic time lab was effective at improving student conceptions of Earth history as evidenced by scores on the exam assessment question. The revisions moved the timeline activity from a confirmation level where students were simply

observing a phenomenon to a structured and guided level where students played an active role in the analysis of results and drawing of conclusions. This increased involvement in the scientific inquiry process appears to help students formulate more accurate conceptions of geologic time and Earth history. In addition, the prediction component reveals student misconceptions, forces students to confront them, and may be an important part of helping students develop more correct conceptions.

The final exam question can be useful in assessing student conceptions of Earth's history as a result of the lab experience. Students who score a 0, 1, or 2 out of 9 are still struggling with not only the timing of all the events but also the relative order of most if not all events. Students who score a 3 tend to group the events toward the middle of their timeline (figure 2.7) and have not developed an accurate conception of the scale of Earth's history. Students who score a 4 or 5 are beginning to recognize that some events like the appearance of *H. sapiens* and the extinction of non-avian dinosaurs are fairly recent phenomenon on the geologic time scale. The most frequent score amongst all students was a 6 of 9. Students who score a 6 of 9 recognize that there is some clustering of events near the end of the timeline, but view the origin of life as occurring too late (minus 2 points) and the origin of hard parts occurring too early (minus 1 point; figure 2.7). Another less common 6 point score is students who place all events at roughly equal spacing along the entire timeline thereby getting the origin of life and *H. sapiens* correct. Students who score a 7 fall into two categories, those who view the origin of life occurring too late (minus 2) or those who think that hard parts and dinosaurs originated much too early. The only misconception that students scoring an 8 have, is that organisms with hard parts evolved much earlier than they actually did (figure 2.7).

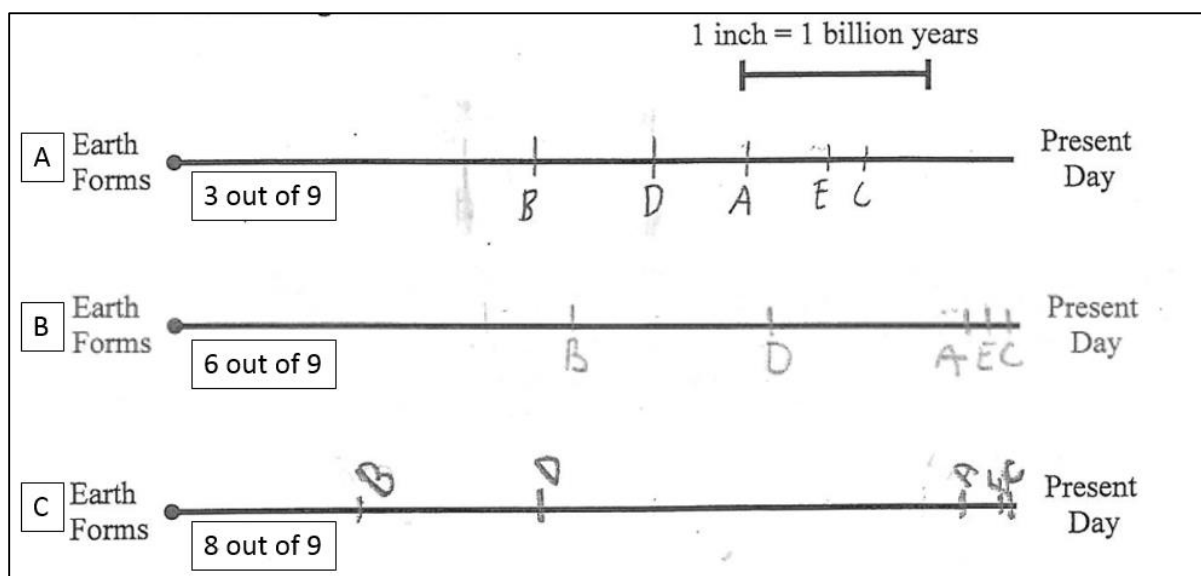


Figure 2.7 Example student responses to final exam Earth history question. A) Score 3 out of 9 B) Score 6 out of 9 C) Score 8 out of 9

These results reveal which misconceptions persist, even after inquiry revisions were made to the lab. One of the most persistent misconceptions students seem to retain is in regards to the origin of life on Earth. Students commonly place the origin of life much later than the known evidence for life on Earth around 3.5 billion years ago and also underrepresent the amount of time that microbial life flourished in the absence of animal life. This concept is presented during the timeline when students see the distance between stromatolite fossils and all other fossils on their 46 foot timeline. They also answer a question about when life originated on their pre-lab. Future revisions to the lab could incorporate more student involvement with this concept. The other common misconception is students interpreting the origin of hard parts to occur too early. While there is a lot of emphasis in the revised lab on the fact that organisms with high preservation potential are a recent phenomenon over geologic time, it is possible that students are not distinguishing the nature of living microbes from microbial fossils preserved as rock which they encounter in lab (stromatolites and algae). Adding a fossilization component to future revisions of the lab may help address this issue.

CHAPTER 3: INSTRUCTIONAL CHANGE IN A LECTURE CLASS

3.1 Background

In order to attract and retain STEM graduates, reform initiatives stress the need to change the way introductory STEM courses are being taught (NRC, 1999; PCAST, 2012). These reforms stress the adoption of reformed teaching strategies that have been showed to promote positive student outcomes. Examples of these techniques include peer instruction (Crouch and Mazur 2001), lecture-tutorials (Kortz et al., 2008; LoPresto and Murrell, 2009), involving students in demonstration predictions (Crouch et al. 2004), and a variety of in-class, student-centered activities (McConnell et al., 2003; Knight and Wood, 2005). The literature is full of reformed teaching strategies from every discipline within STEM and describe techniques for improving student outcomes from smaller laboratory courses (Luckie et al., 2012) to large lecture courses (Walker and Cotner, 2008; Deslauriers et al., 2011). All of these techniques involve students playing an active role in the learning process by working in pairs or small groups to answer instructor provided questions or problems. These activities provide the instructor with an opportunity to formatively assess student learning or prior knowledge and adjust instruction as needed.

With such a large collection of reformed teaching in the literature, it begs the question, how many introductory STEM instructors are aware of and adopting reformed teaching? Instructors have been surveyed on their teaching style and techniques within three disciplines. A survey of 237 engineering department heads found that 82% of them were aware of reformed teaching but only 36% reported awareness of their use by faculty (Borrego et al., 2010). A survey of over 2000 geoscience faculty found that lecture was still the predominant teaching method, but over 50% of instructors reported using some form of interactive student activity at least weekly (Macdonald and Manduca, 2005). Finally, in a web survey of 722 physics instructors, it was found that 87% were aware of reformed teaching strategies and just under half (48.1%) reported they used them (Henderson and Dancy, 2009).

While the number of instructors who have reported adopting reformed teaching seems encouraging, these self-reported results may be overestimating the actual adoption rates. All three surveys had response rates at or below 50%, so the collected data could be reflecting a nonresponse bias if instructors using reformed teaching strategies were more likely to respond. In a follow up with 72 physics professors in the Henderson and Dancy (2009) study, it was found that most instructors using peer instruction did so with modifications that may reduce their efficacy (Turpen et al., 2010). Ebert-May et al. (2011) utilized classroom observations to show that only 20% of instructors who reported implementing reformed teaching practices after professional development actually moved toward a more student-centered classroom. In light of these results, the number of faculty using reformed teaching strategies or using them effectively may actually be lower than self-report surveys suggest. An additional finding of the Henderson and Dancy (2009) study was that reformed teaching strategies had a 32 to 54% discontinuance rate. A follow up analysis concluded that among faculty who had tried reformed teaching strategies, 1/3 discontinue use, approximately 1/3 become light adopters, and 1/3 heavy adopters (Henderson et al., 2012).

Even though a majority of faculty surveyed had awareness of reformed teaching strategies, the less than ideal adoption rate and discontinuance rate of reformed teaching strategies suggest that barriers exist for instructors in changing their teaching practices. Instructors report that the most prevalent barrier to the adoption of reformed teaching strategies is time (Sunal et al., 2001; Henderson and Dancy, 2007; Dancy and Henderson, 2010). Instructors note that they do not have sufficient time to learn about reformed teaching strategies and revise courses to implement these strategies. Instructors also frequently mention factors such as limited training in the use of reformed teaching strategies, lack of resources, lack of confidence in the strategy, and lack of institutional support (Walczyk et al., 2007; Henderson and Dancy, 2009). It has also been suggested that many faculty may struggle with professional identity, where being seen as a great researcher holds higher status than being a great teacher, especially at institutions that have a significant research culture (Brownell and Tanner, 2012).

Professional development models and programs have been generated as a means to help faculty with the adoption of reformed teaching strategies. However, as results from Ebert-May et al. (2011) showed, the effectiveness of such programs are uneven at best. After professional development programs or workshops, instructors may desire change, but many of the cited barriers prevent these changes or else instructors become dissatisfied with reformed teaching and discontinue its use. Short-term workshops that present reformed teaching strategies to instructors are among the least effective professional development methods (Garet et al., 2001).

Another possible barrier to the continued use of reformed teaching strategies, and one that is rarely reported, is an instructor's beliefs about teaching and learning. The teaching beliefs that an instructor holds are predictors for their behavior or instructional practice (Nespor, 1987). Studies have shown that a teacher's beliefs about teaching can impact their implementation of curricula (Brickhouse, 1990; Cronin-Jones, 1991) or scientific inquiry lessons (Roehrig and Luft 2004). Henderson (2005) studied an instructor who was revising his teaching methods and was part of a national program to change the way physics was taught. Through the use of interviews, Henderson reported that one of the main reasons the instructor did not reach his desired level of improvement was the inability to overcome his own instructional model and change his teaching beliefs (Henderson, 2005). Roehrig and Kruse (2005) found similar results, where the degree of instructional change in twelve chemistry teachers' practices due to the introduction of reform-based curricular materials was limited by their beliefs. Some portion of the disconnect between instructors who choose not to adopt reformed teaching strategies or who discontinue their use may be attributable to incompatible teaching beliefs.

These observations highlight the importance of evaluating and measuring instructional beliefs as part of educational reform programs. If the goal is to get more instructors to adopt and continue using reformed teaching strategies, we must ensure that their beliefs are also becoming more reformed-based. Professional development models need to consider all the barriers to instructional change, including time, training, resources, institutional support and teaching beliefs. While methods courses for pre-service teachers

have been shown to shift teachers' beliefs to a more student-centered perspective (Wilkins and Brand, 2004; Pilitsis and Duncan, 2012), it is unclear whether professional development programs for college faculty do the same.

In order to successfully change the way undergraduate STEM courses are taught, new professional development programs will need to be developed that effectively promote instructional change and overcome barriers to change. Effective programs need to last for a significant period of time and also involve a high number of hours (Garet et al., 2001). Professional development is more effective if instructors are able to take an active role in the development process through implementing strategies, observing other instructors, and receiving feedback (Garet et al., 2001). Based on Henderson, Beach, and Finkelstein's (2011) review of change strategies and literature on effective professional development, the NRC (2012) suggests that at least two of the following strategies are necessary as part of successful programs for changing instructional practice: 1) sustained, focused efforts, lasting 4 weeks, one semester, or longer; 2) feedback on instructional practice; and 3) a deliberate focus on changing faculty conceptions about teaching and learning.

A collaborative model for professional development may provide a way to incorporate the NRC's suggested features of successful programs and also overcome some of the barriers to instructional change. Working with a collaborator experienced in reformed teaching would reduce the time constraints on faculty for revising courses while providing on-site or in-class training on the implementation of reformed teaching strategies. This collaborative approach may result in a more positive experience with reformed teaching which in turn could lead to the achievement of desired outcomes, continued use of reformed teaching strategies, and promoting more student-centered beliefs in the instructor. One example of such a program is the University of British Columbia's Science Education Initiative (SEI) which provides faculty interested in reforming their teaching with a collaborative Science Education Specialist (SES). Only one faculty member out of 70 working with a SES discontinued the use of reformed teaching strategies (Wieman et al., 2013), a discontinuance rate much lower than that reported by Henderson, Dancy, and Niewiadomska-Bugaj (2009, 2012). Two case studies in Astronomy have used a similar

collaborative approach where an instructor seeking to change their instructional practice was aided by an education specialist from an education or teaching department (Brogt, 2007; Bailey and Nagamine, 2012). Brogt (2007) served as the course TA in addition to collaborator thus freeing up time for the instructor to focus on implementing reformed teaching strategies, whereas Bailey (2012) co-taught alongside the instructor. In a similar model from physics, a new instructor co-taught with an experienced instructor who had significant experience with reformed teaching strategies (Henderson et al., 2009). Interview data reflected that the instructors experienced a shift in their beliefs about instruction in all three of these case studies.

In the fall of 2012, Jamie (pseudonym), a faculty member in the NCSU Marine, Earth, and Atmospheric Sciences department approached the discipline-based education research faculty member to express their desire to change the way they taught an introductory geoscience course. Figuring out how to best help Jamie in revising an introductory science course to be more-student centered led to the idea of using the experience as a case study in collaborative professional development. Jamie was assisted in revisions by the author (PI), a graduate student in the geoscience education research group. In addition to collecting data throughout the process, the PI assisted Jamie in revising lessons, creating student activities, grading, and training in the use of reformed teaching strategies. This model of professional development that is occurring in the classroom with the aid of a reformed teaching advisor is being termed situated instructional coaching. There were four research questions driving the case study:

1. How would the instructor implement the teaching practices associated with the redesigned lessons?
2. How well would the instructor learn to create or redesign lessons that incorporate reformed teaching strategies?
3. What effect would the situated instructional coaching experience have on the instructor's teaching beliefs?
4. How would students respond to the reformed teaching strategies as part of their learning experience?

3.2 Methods

Course Revisions: The course to be revised was a medium-sized, introductory-level geoscience course with no associated lab and an enrollment cap of 70 students. The course was taught during two 75 minute class periods a week. In the past, Jamie co-taught the course and was responsible for teaching half the material (12-14 class periods.) In the spring of 2013, Jamie provided the PI with all the PowerPoint presentations from a previous iteration of the course. Among the twelve presentations, there was an average of 95 slides per 75 minute class, the minimum being 50 slides and the maximum 138. Although no observational data is available from the previous iterations of the course, the slide numbers, content coverage, and informal conversations with Jamie allude to a teacher-centered, lecture-dominated instructional style.

The revised course was built upon the PowerPoint presentations that had previously been created and used in prior semesters. The content covered in these twelve presentations was spread out over the 28 class semester, with a few topics added to fill in some needed gaps. Based on these changes, Jamie and the PI outlined a syllabus that would allow for a reasonable amount of content coverage and time for student activities in each class period. The syllabus was further divided into seven distinct modules based on common content themes, with each module containing three to six class periods.

A three phase system was used in creating the revised lessons for each class. For the first third (9 classes), all revisions and student activities were created by the PI, which allowed the instructor to focus on implementing and becoming comfortable with a student-centered instructional style. For the middle part of the course, the PI and instructor worked together on the revisions, and during the last third of the course all revisions were primarily handled by the instructor with minimal assistance from the PI.

Designing each new lesson was done using the Integrated Course Design model (ICD; Fink 2009). The ICD model focuses on five components of course design: situational factors, learning objectives, learning activities, feedback and assessment activities, and integrating the course. Using the ICD model, course design begins with the construction of learning objectives. Based on these objectives, learning activities, feedback, and assessments

are developed. Ensuring that these components are well integrated into the classroom teaching and learning environment is the final step (Fink, 2009).

While many of Jamie's original PowerPoint presentations contained objectives at the beginning, they were mostly teacher-centered or not measurable. Example objectives included "To introduce chemical concepts that underlie radioactive dating" or "To understand the changing surface of the planet and how it related to climate, environment, and possibly to extinctions and origins of species." The former focuses on what the instructor will do, while the latter is from the student perspective but leaves unclear what the student will do to demonstrate understanding and is therefore difficult to assess. Consequently, four or five new learning objectives at varying levels of Bloom's taxonomy (Bloom et al., 1956) were written for each of the revised lessons. The new learning objectives used appropriate action verbs that would allow for measurement of student learning on formative and summative assessments. Revising one of the above examples, the resulting learning objective is stated from the student perspective as "I can explain what happens during radioactive decay using the terms element, isotope, and half-life."

After drafting the learning objectives, conceptual multiple choice questions (conceptests) and student worksheets were created to accompany the lesson. Students responded to conceptests using clickers to indicate their answer choices, providing the instructor and student with immediate feedback. Conceptests and worksheets served not only as formative assessment tools, but as a way to track student participation and attendance. Student worksheets were loosely modeled after lecture tutorials (Kortz et al., 2008) which require students to answer questions related to material just presented and scaffold the students toward more complex questions. The most common complaints about the instructor on previous student course evaluations was the fast pace of lecture. The worksheets and associated activities were designed to create breaks in lecture and address this concern. Activity prompt slides were used amidst the lecture to not only indicate which part of their worksheet students should work on, but to also point out the relevant learning objectives associated with the activity. Working in pairs or small groups was encouraged and often necessary for many of the activities. The activities varied by lecture and often included

multiple choice and short answer questions, evaluating or writing hypotheses, solving problems with provided data, or learning reflection questions. (An example worksheet is included in Appendix D)

Using the online course software (Moodle) available at NCSU, quizzes and learning journals were created for each of the seven modules. Each quiz was composed of 10 random questions generated from a question bank related to the module topic. Students could attempt each quiz up to three times before the beginning of the next module, with their highest grade being recorded. Learning journals were also created through Moodle, with one due at the end of each module. Learning journals provided an opportunity for students to reflect on their learning and generally consisted of 2-3 questions. Common learning journal activities included students ranking their confidence in learning objectives, writing about learning objectives, posing questions regarding something they are unsure of, and reflecting on study habits and exam performance. Note outlines based on the PowerPoint presentations were also created and made available to students before class by posting them on the Moodle site. Finally, two new mid-term exams and a final exam were written to align with the new learning objectives and assess students at various levels of Bloom's taxonomy (Bloom et al., 1956).

Data Collection Instruments: The Reformed Teaching Observation Protocol (RTOP; Appendix E; Sawada and Piburn 2002) was used along with the supplemental rubric created by Budd et al (2013) to characterize the level of reformed teaching occurring during each class period. The RTOP rates a lesson on 25 items across 5 different categories: (1) lesson design and implementation, (2) content propositional knowledge, (3) content procedural knowledge, (4) Classroom culture student-student interactions, and (5) classroom culture student-teacher relationships. Each item is scored from 0-4 with the overall RTOP score for a class ranging from 0-100. The PI observed and obtained RTOP scores for all but two classes taught by the instructor. These two classes were observed by peers who had undergone the same three phase RTOP training and calibration as the PI. An additional observer was also used during four of the classes to ensure reliability of the PI's RTOP scores. Inter-rater agreement for total RTOP score among the four shared observations was

excellent ($r = 0.95$). No observational or RTOP data was available for prior iterations of the course.

The Teacher Beliefs Interview (TBI; Luft and Roehrig 2007) was used to capture the instructor's beliefs about teaching and learning and to also detect any changes in beliefs that occurred during the course redesign and implementation process. The TBI interview consists of seven short and focused questions pertaining to teaching and learning (Table 3.1).

Answers to the seven questions are then coded and classified by one of five descriptors: Traditional, Instructive, Transitional, Responsive, and Reformed. Traditional and Instructive are considered teacher-centered views, where responsive and reformed are considered student-centered. Transitional views are where the instructor is beginning to consider the student role, but more from an affective perspective. Using a technique adopted from Roehrig & Kruse (2005), the coding of each question's response can be converted to a number, with 1 point for a traditional response and on up to a 5 for a reformed response. An interview of all 7 questions can then be assigned a TIBI score between 7 and 35.

Table 3.1 Teacher Beliefs Interview (TBI) questions (Luft and Roehrig 2007).

-
1. How do you maximize student learning in your classroom? (learning)
 2. How do you describe your role as a teacher? (knowledge)
 3. How do you know when your students understand? (learning)
 4. In the school setting, how do you decide what to teach and what not to teach? (knowledge)
 5. How do you decide when to move on to a new topic in your classroom? (knowledge)
 6. How do your students learn science best? (learning)
 7. How do you know when learning is occurring in your classroom? (learning)

During this study, an initial pre-course TBI interview was conducted in April 2013, well before the start of the fall semester to determine the instructor's initial beliefs about teaching and learning. A second mid-course interview was conducted 5 weeks into the course after the first exam in late September of 2013. A third end-of-course interview was conducted immediately after the last day of classes in early December 2013 and a final post-course interview was done in mid-January of 2014. All interviews were conducted and

transcribed by the PI, and interviews were co-coded by the PI and a peer. It should be noted that no attempt was made to coach Jamie into more student-centered beliefs during the study. The purpose of the study was to see what effect change in practice would have on Jamie's beliefs, so discussions that could lead Jamie to student-centered answers on the TBI were avoided throughout the project. Additionally, interviews were not transcribed, coded, and scored until after the final interview was complete.

After the final TBI interview, an informal, loosely-structured interview was conducted to allow Jamie a chance to reflect on the experience. This interview used three simple questions as reflection prompts: 1) What went well? 2) What did not go so well? and 3) What would you change in the future? While data collected during this interview were not used to answer the guiding research questions, the responses help to frame some of the discussion below.

Jamie also completed a Beliefs about Reformed Science Teaching and Learning (BARSTL) survey before each interview (Appendix F; Sampson et al., 2013). The BARSTL is a validated survey based on national science education and reform efforts. The survey is composed of 32 items divided up amongst 4 subscales: (1) how people learn about science, (2) lesson design and implementation, (3) characteristics of teachers and the learning environment, and (4) the nature of the science curriculum. The BARSTL survey is scored from 32 to 128 points. Respondents indicate their level of agreement with a statement by circling a number 1 through 4, with 1 being strongly disagree, 2 disagree, 3 agree, and 4 strongly agree. Half the statements are phrased from a traditional perspective and thus are reverse scored where circling a 1 (strongly disagree) earns four points.

Midway through the semester, a modified Group Instructional Feedback Technique (Angelo and Cross, 1993) survey was administered to gauge student response to the instructional strategies being used. This was an anonymous survey asking students to answer the following three questions as thoroughly as possible:

1. Give two examples of specific things that your instructor does that *help you learn* the material for this class.
2. Give two examples of specific things that your instructor does that *make it more difficult for you to learn* the material for this class.

3. Suggest one specific practical change that your instructor could incorporate into his/her teaching to help you improve your learning in this class.

3.3 Results

RTOP: A total of 24 classes were taught over the semester and the average RTOP score was a 44.9 (represented by the dashed line in Figure 3.1). The highest scoring class was a 74 (class 13) and the lowest a 31 (class 28; Figure 3.1). In the four classes where 2 observers were used, the average score was reported although scores between both observers never varied by more than 4 points. Missing class numbers (6, 7, 10, 21) represent two days that the PI taught in Jamie's absence and two exam days. The shaded regions of the graph represent generalized score characterizations from Budd et al (2013) where scores of ≤ 30 represent teacher-centered, lecture-based classes, 31-49 are transitional classes with moderate student talk and activity, and ≥ 50 are student-centered active-learning classrooms. RTOP scores for each item in every class can be seen in Appendix G.

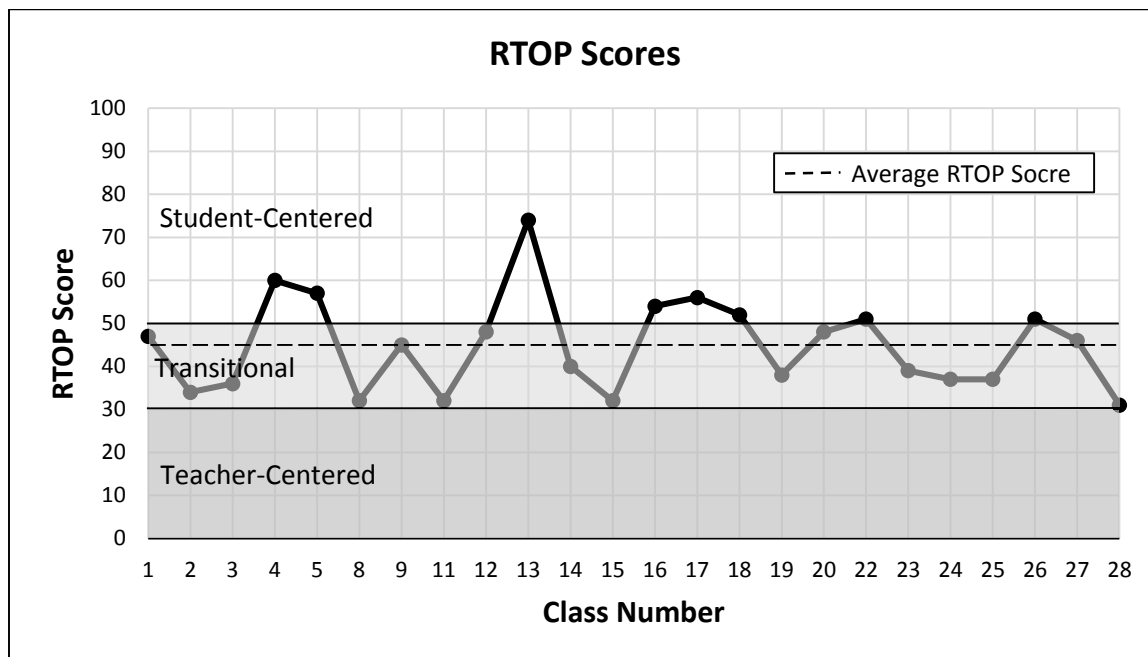


Figure 3.1 RTOP scores from each revised class. Missing days represent exams or instructor absences. Score ranges for student-centered, transitional, and teacher-centered taken from Budd et al. (2013).

RTOP data show that the revised course was never taught below a transitional level, and 1/3 of the classes were student-centered (8 of 24), scoring over a 50 on the RTOP (Figure 3.1). Class 13 was the highest scoring, earning a 74. This class covered a topic that Jamie had never taught before, was not personally confident in, and disliked even though it was a necessary topic for the course. This topic came up during the first TBI interview, and Jamie expressed these strong feelings by saying “I don’t do it, I don’t want to do it, I think it’s boring, but it’s important. And so I’ve always co-taught that with somebody who does do it.” Fortunately, a very student-centered activity was found in the literature that had been proven to promote student learning on the topic. The activity required that students spend most of class time working in groups with a few breaks for class discussions. Jamie was hesitant to use the activity at first, but ended up enjoying the experience and utilized the underlying analogy throughout the rest of the semester.

Two specific examples of what the revised class periods looked like are presented below. While the ICD model used to revise each class period allowed for some consistency, the student activities that were created often dictated the format and structure of each class. Some classes ended up with better integration than others, as the examples below illustrate. Table 3.2 below illustrates one of the lowest RTOP scoring classes, which involved some student activity at the beginning and end of class, but retained a large block of lecturing in the middle. This class came during the middle of the semester when Jamie and PI were co-creating the lessons.

Table 3.2 Example of a revised class. Class #15 with an RTOP score of 32.

Time	Activity
0-8 min	Started class by presenting the learning objectives. This was followed by a one slide review from last class and three concepttest questions to assess student knowledge of the concept.
8-55 min	Instructor lectured on concepts of the lesson. Teacher fielded three student curiosity questions related to the lecture content.
55-65 min	Students worked together in groups of two or three on a Venn diagram activity followed by a shout out review of the correct answers. Class ended 10 minutes early.

Table 3.3 shows a higher RTOP scoring class that involved more student-centered activities and smaller blocks of lecture time. Over a third of the class time (~38%) involved student talk or activities, which provided breaks in the lecture portions of class. This class came from the final 1/3 of the course, where Jamie was largely responsible for lesson design and creating the student activities.

Table 3.3 Example of a revised class. Class #26 with an RTOP score of 51.

Time	Activity
0-7 min	Introduced topic and four learning objectives. Class started with a brainstorming think-pair-share.
7-20 min	Began with a conceptest question to assess student prior knowledge followed by lecture on the first concept.
20-30 min	Lectured on second concept. One conceptest question to assess student learning. Teacher answered three student questions, one of which shifted the direction of class briefly and lead to another student question.
30-37 min	Students worked together on an interpretive drawing activity. The instructor then provided a photograph of the drawing subject and there was a short class discussion on the implications of the activity to the class topic.
37-45 min	Lectured on third concept. One student question answered by instructor.
45-54 min	Students worked on a group activity designed to have them make connections between their prior or common knowledge and the topic of the lesson.
54-70 min	Lectured on the fourth concept. Two conceptest questions to assess student learning. One student question fielded by instructor.
70-75 min	Students finished with a reflection activity, writing what they thought were the three most important points covered in class.

TBI Interviews and TBI Scores: Results from the TBIs showed an overall increase of 7 TBI points from pre- to post-course (Figure 3.2). The 7 point shift is accounted for as a result of Jamie changing beliefs on questions #1, 2, 3 and 6 (Figure 3.3). On question #1 Jamie went from a teacher-centered to a transitional view, on questions #2 and 6 from a transitional to a student-centered view, and on #3 from a teacher-centered to a student-centered view. Question #4 was one that Jamie seemed to have dichotomous views on, and would express either a teacher- or student-centered viewpoint. Questions #5 and 7 showed

little or no change throughout the course revision process. Further analyses of TBI results with sample responses for each question are provided below.

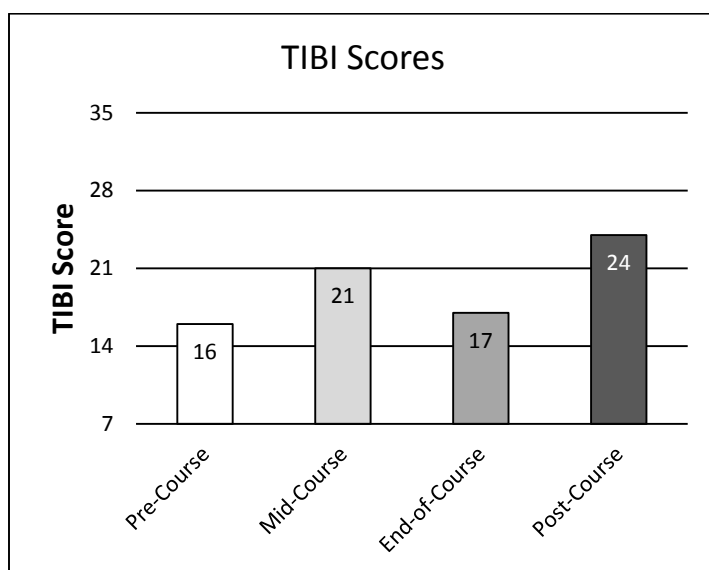


Figure 3.2 TIBI scores.

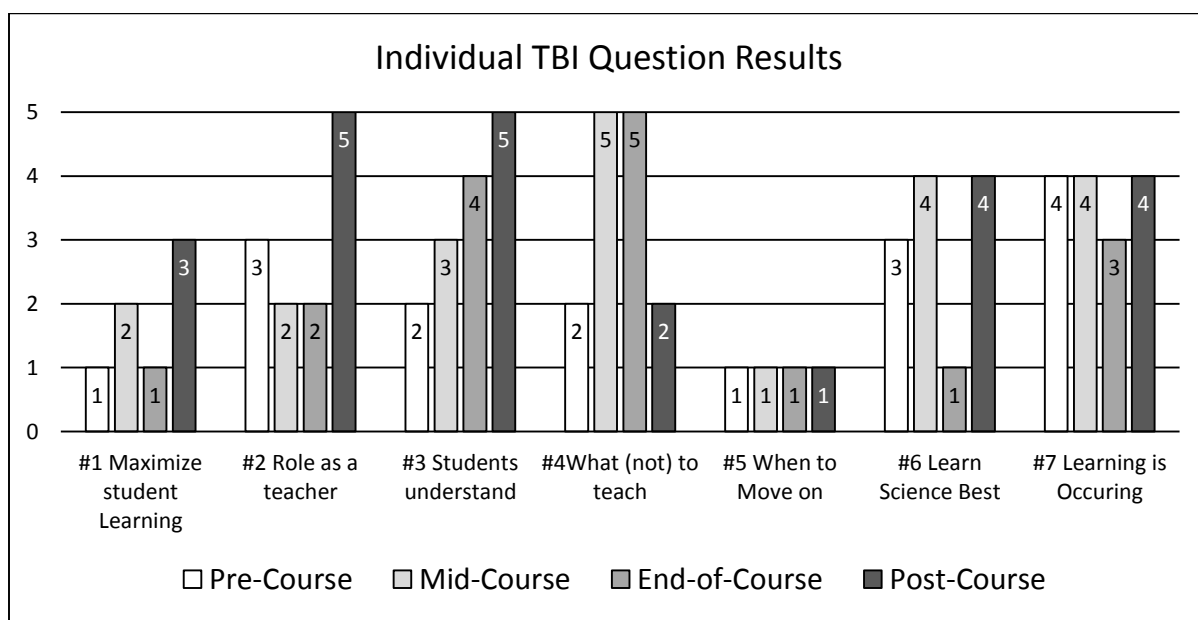


Figure 3.3 TIBI score for each TBI question across all four interviews. See Table 3.1 for complete text of TBI questions.

#1 How do you maximize student learning in your classroom? Jamie maintained a teacher-centered belief on this question from pre- to end-of-course. Responses were focused on providing information in a structured environment or monitoring student actions: “And so what I do is give you the background that you need to understand...I provide them with notes to follow...by asking if everyone is on the same page.” By the final interview, after Jamie had had time to reflect on the experience, the answer had become transitional.

I think hands on experience and observation, If you give them the opportunity to see things...I think asking them questions that all are centered around what you want to pull out of them makes them think more than if you just tell them the information or if they read the information.

This response reflects a transitional belief that students should be involved in the classroom environment.

#2 How do you describe your role as a teacher? From pre- to end-of-course, Jamie maintained an instructive belief regarding this question. Jamie often referred to the term facilitator. From the responses it was suggested that Jamie saw facilitating as providing an experience for the student to learn. During the pre-course interview, Jamie did express an affective transitional belief regarding students’ fear of science: “many freshman in particular are scared to death of science...So I think to start by trying to un-threaten science.” The post-course answer to this same question revealed a reform-based view that considers the prior knowledge and interests of the students.

Giving students a framework, starting with where they’re at, building the root of the tree and then hanging the branches off is more your job than giving them de novo information. They won’t retain it if it’s just memorizing a bunch of isolated facts. You need to give them a way to tie them to what they already know and what they want to know and teach it.

#3 How do you know when your students understand? On this question Jamie showed a steady progression from an instructive view on the pre-course interview to a reform-based view on the final post-course interview. Jamie’s initial view focused on students being able

to repeat presented information. “I try to ask questions in the lecture and if they can’t answer the questions I figure they’re not getting it...I guess ultimately it’s how they do on the test.” By post-course Jamie expressed a reform-based view. “...different applications of the basic concept. When they can do that, when they can take the concept and apply it in novel situations, I think they got it.”

#4 In the school setting, how do you decide what to teach and what not to teach? This was a question that Jamie seemed to hold strongly dichotomous views on. During the pre- and post-course interview, Jamie expressed instructive responses, reflecting a teacher focus on deciding what to teach with responses like “I basically go on my own experiences” or “I don’t teach what I don’t like.” During the mid-course and end-of-course interviews Jamie expressed reform-based views with a student focus. On the mid-course interview Jamie stated “I struggle with what does a future banker or accountant really need to know about geology?...it’s more about looking and learning how to see their world,” and from the end-of-course “first of all, I want to be able to have them relate everything they learn about geology to the world they live in because it’s the only way it’s going to be pertinent.”

#5 How do you decide when to move on to a new topic in your classroom? This was a question where Jamie never expressed anything beyond a traditional view of the teacher controlling the direction of class. Every answer reflected the idea of sticking to the syllabus, from “I guess when I’m setting up the syllabus...” on the pre-course interview, to “I decide when I’m making up my syllabus what topics I want to cover; I move on according to the syllabus rather than whether or not they’re getting it, and that’s probably wrong” on the post-course interview. As in the previous quote, in most interviews Jamie acknowledges or hints that this may not be the best strategy, but never moves beyond a traditional belief.

#6 How do you students learn science best? Jamie initially expressed a transitional view on this question and on later interviews more responsive views. The traditional coding on the end-of-course interview is likely due to the inexperience of the PI as an interviewer. The PI failed to realize during the interview that Jamie had not really provided an answer to this question, even after a follow up probe. This led to a traditional coding for the response. However, in both the mid- and post-course interview, Jamie expressed responsive views,

acknowledging that students learn science best by not only doing but also interpreting. “By doing it...if they make an observation that they are surprised by, then they need to ask the question ‘why did this happen this way?’...They’ve got to be observing, they’ve got to be asking questions.”

#7 How do you know when learning is occurring in your classroom? Jamie fairly consistently expressed responsive views to this question, including some form of student-student or student-teacher interaction as a sign of learning. Jamie’s responses usually included comments about students asking questions on the topic, talking to each other, or having discussions. Responses included “When they ask questions” and “I can see them playing with the samples, turning them upside down, trying to talk about them” on the pre-course interview to “when they get so excited about an idea that they actually look things up on their own or ask questions that are outside the box” on the post-course interview.

BARSTL Survey: The BARSTL survey results showed an overall increase of 6 points from pre- to post-course (Figure 3.4). There was a slight three point drop from mid- to end-of-course. Three questions on the survey results were identified (#5, 19, and 23) where Jamie went from scoring a 3 (pre-) to a 4 (mid-) to a 3 (end-of-) and back to a 4 (post-). The slight vacillation on these three questions led to the drop in scores between mid- and end-of-course where there would have otherwise been a plateau.

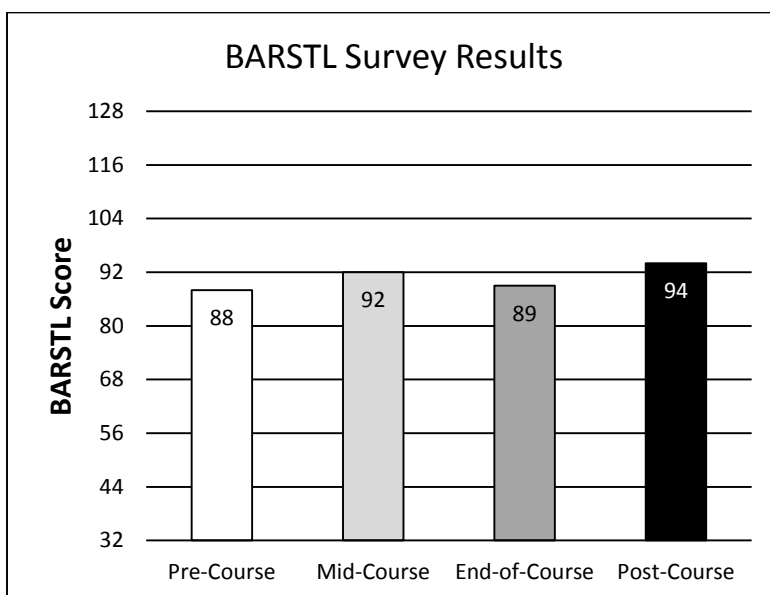


Figure 3.4 BARSTL survey results.

With Likert-response surveys there is an unclear scale of difference between the ordinal values selected by the respondent. The degree of difference between ‘agree’ and ‘strongly agree’ varies between individuals and direction of agreement plays a bigger factor in score changes (Peabody, 1962). Changes from ‘agree’ to ‘disagree’ (score changes from 2 to 3 or 3 to 2) are also likely to represent a more fundamental shift in viewpoint. From pre- to mid-course, Jamie showed a positive scoring viewpoint change from disagree to agree on items #9, 17, and 24. These items are related to student independence and talk in the classroom (the full text of these questions can be seen in Table 3.4). By end-of-course Jamie also switched to agreement on question #32 related to the focus of scientific curriculum. The table also shows three positive scoring items where Jamie’s level of agreement changed, either from ‘agree’ to ‘strongly agree’ or from ‘strongly disagree’ to ‘disagree.’

Table 3.4 BARSTL survey Items showing change from Pre- to Post-Course.

	Item#	Scores				Item Text
		Pre-	Mid-	End-	Post-	
Positive Scoring Viewpoint Change	#9	2	3	3	3	During a lesson, students should explore and conduct their own experiments with hands-on materials before the teacher discusses any scientific concepts with them.
	#17	2	3	3	3	Students should do most of the talking in geoscience classrooms.
	#24	2	3	3	3	Geoscience teachers should primarily act as a resource person; working to support and enhance student investigations rather than explaining how things work.
	#32	2	2	3	3	A good science curriculum should focus on the history and nature of science and how science affects people and societies.
Positive Scoring Agreement Level Change	#4*	1	1	1	2	Students are more likely to understand a scientific concept if the teacher explains the concept in a way that is clear and easy to understand.
	#13	3	3	4	4	Lessons should be designed in a way that allows students to learn new concepts through inquiry instead of through a lecture, a reading, or a demonstration.
	#28	3	3	3	4	The science curriculum should encourage students to learn and value alternative modes of investigation or problem solving.

*= reverse scored (strongly disagree earns 4 points)

GIFT Survey: Student responses (n=50) to the three question GIFT survey were coded and grouped into similar responses. Figure 3.5 shows the results from each question. Only items that were mentioned by a minimum of 5 students were reported. The number one response that students gave in reply to what the instructor does to help them learn the material was the in-class activities (n=31), followed by the provided note outlines (n=24). The number one response given by students as to what makes it difficult to learn the material was that the instructor lectures too quickly (n=30). This led to the number one suggestion on how to improve learning being to slow down when lecturing (n=19).

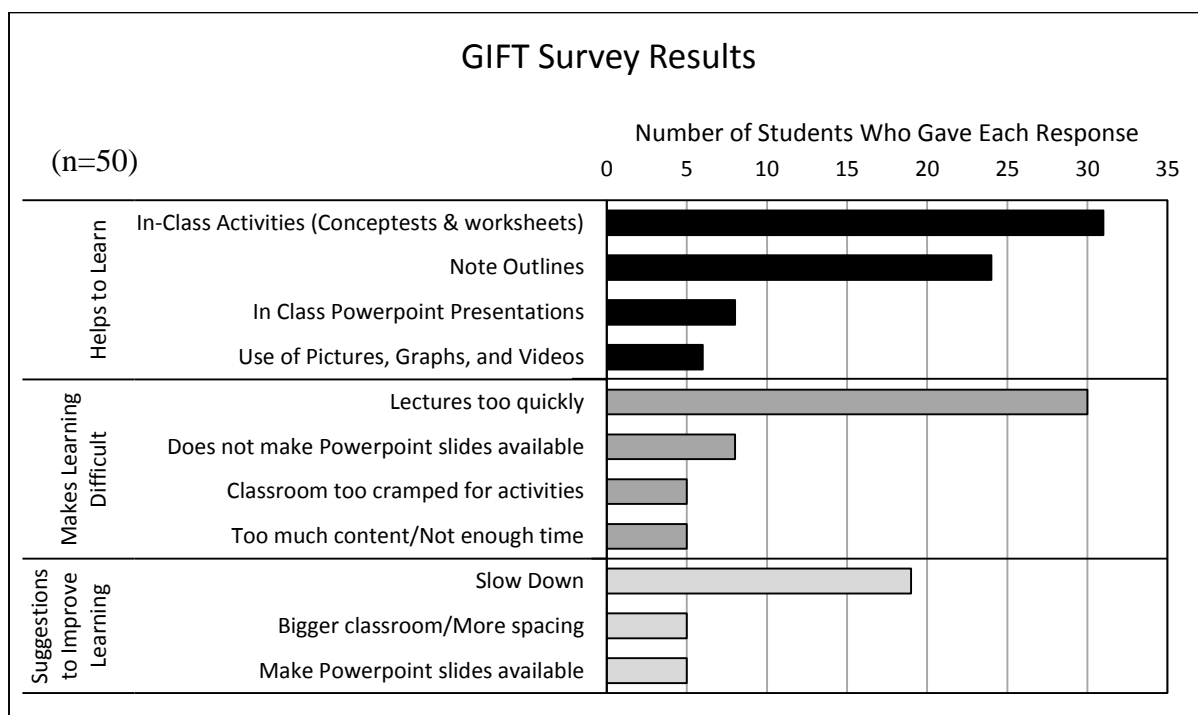


Figure 3.5 GIFT survey results. Only items mentioned by a minimum of 5 students were reported.

3.4 Discussion

Research Question #1: How would the instructor implement the teaching practices associated with the redesigned lessons? The RTOP data (Figure 3.1) provide evidence that Jamie was effectively able to implement the redesigned lessons and reformed teaching strategies. No class was taught with a teacher-centered style, and every class scored more than a 30 on the RTOP. This is no minor accomplishment for an instructor with a very traditional teacher-centered style and traditional teaching beliefs coming into the experience. There was a concern at the start of this study that Jamie would resort to traditional methods when it came time to teach the revised course. Even with over 20 years of experience teaching, Jamie admitted to having a fair amount of anxiety over teaching and public speaking. Talking non-stop during lecture is a coping mechanism, which came up during the informal interview:

“I like to turn all the lights off and hide behind the slides. They’re not looking at me, they’re looking at the slides. I’m really shy. So having to get up there and do these things that are out of my comfort zone like stop in the middle of lecture and give them time to work on their own, that’s hard for me.”

Having the PI as a collaborator in the classroom could have eased Jamie’s concern over using student activities and effectively implementing the new lessons. This also allowed for post-class reflections and discussions on the implementation of the teaching practices between the PI and Jamie. Additionally, the presence of a collaborator in the classroom added a level of accountability, ensuring that Jamie did not just slip back into traditional teaching practices that were more comfortable.

This is not to say that implementation was flawless or even went smoothly in all classes. Many of the lower RTOP scoring classes had a student-centered design, but less than ideal implementation resulted in them scoring in the transitional range. One example is class 9 which contained a student debate component centered on a contentious issue in the discipline. The class was divided in half, and each half worked in small groups to formulate supporting evidence for one side of the debate. Finally students would present the case for their side and groups from the other side would get a chance to counter the point. Jamie hurried the students through the activity in 10 minutes, an insufficient amount of time for them to achieve all their goals. Most groups were unable to fully formulate arguments, and only a few students presented their cases before Jamie moved on to lecturing on the topic. This impatience with student activities was common throughout the semester and is likely tied to Jamie’s traditional beliefs regarding when to move on to a new topic in the classroom. A strong desire to rigidly stick to the syllabus and get through the material often led Jamie to rush student activities so as not to run out of lecture time to cover the material. In the case of class 9, it actually ended up finishing 19 minutes early. This class would most likely have earned a student-centered score ($RTOP \geq 50$) if this time would have been used for further student-student interaction and class discussion associated with the planned activity.

Another factor may also partially explain some of the lower RTOP scores. Due to the topic of the course, Jamie and the PI had to design and create most student activities and

conceptests, as there were few appropriate activities available in the literature or online. Jamie and the PI were developing or modifying PowerPoint presentations, writing learning objectives, generating conceptests, and creating student activities and worksheets for every class. Exam questions, online quiz question banks, and learning journals were also being created along the way. These were often time consuming tasks, and due to time constraints some lesson designs were less than ideal which partially explains the fluctuating nature of the RTOP results.

Research Question #2: How well would the instructor learn to create or redesign lessons that incorporate reformed teaching strategies? Jamie was largely responsible for creating lessons for the final third of the course, which was comprised of 7 classes following the second mid-term exam. The average RTOP score for these classes was 41.7 which is slightly below the overall average of 44.9. None of the lessons that Jamie created were taught below a transitional level (RTOP 31-49). By the mid-point of the semester Jamie had become very competent in the creation of clear and measurable learning objectives from the student perspective. By the final third of the semester, Jamie had become comfortable with the ICD model (Fink, 2009), and was not only able to create learning objectives, but was also thinking about student activities, feedback, and assessment.

Research Question #3: What effect would the situated instructional coaching experience have on the instructor's teaching beliefs? Data from the BARSTL and TBIs provide evidence that the collaborative experience of revising and teaching a student-centered class resulted in a change in Jamie's teaching beliefs. This result contrasts the findings of Roehrig and Kruse (2005) who saw no change in beliefs among twelve secondary chemistry teachers who adopted and taught a reformed chemistry curriculum. A key difference in these studies is that by seeking out help in redesigning a course, Jamie was likely experiencing a level of discontent with her current practice whereas the chemistry teachers were solely volunteering for a research study. Another key difference in this study was the presence of the PI who served as a collaborator and trainer in the use of reformed-teaching strategies. The PI served as a guide for how the activities and lessons were to be implemented, and played a factor in not allowing Jamie's initial traditional belief set to

impede effective implementation. The collaborator was also available for discussion and reflection after teaching the reformed lessons, which was likely a valuable part of the experience. Also, the teachers in the Roehrig and Kruse (2005) were adopting previously created material whereas Jamie was helping to create the material and perhaps had a sense of ownership in the process.

Jamie experienced the most significant change in beliefs on Questions #1, 2, and 3 of the TBI (figure 2.3). These questions deal with how to maximize student learning, the role as a teacher, and a knowing when students understand. This experience was the first time that Jamie had ever incorporated such a large student role into an undergraduate classroom. In doing so, she was able to see the value of students taking an active role in their learning and this likely influenced her answers to these questions to become more student-centered. When asked during the informal interview about the course revision experience and what went well Jamie stated:

“I think that the chance to break up into small groups to talk over the concepts or work on a guided exercises, I think that went really well. It’s the first time I’ve ever been exposed to anything like that and I think it really did help the students kind of cement. I would have liked to have seen more breaking up into small groups and have them argue, or have them teach something.”

This response reflects not only that Jamie sees the value of active learning to the student, but also provides an opportunity for assessing student learning and understanding by seeing them utilizing and applying knowledge.

Seeing positive student outcomes as a result of using reformed teaching strategies would help to reinforce student-centered views. However, comparing student performance on exams with past iterations of the course was not possible since Jamie didn’t have grade data from when the course was last taught. Additionally, the old exams used assessed students at the lowest levels of Bloom’s taxonomy (knowledge and comprehension), so new exams were written to assess students at various higher levels and to also better align with the new learning objectives. As a result, evidence of positive student outcomes had to come from other sources than student performance.

Results from the GIFT survey revealed that students found the in-class activities to be the most helpful thing the instructor does to help them learn the material. Receiving this feedback that showed students valued being active participants in the learning process hopefully served to reinforce a student-centered view of teaching for Jamie. Jamie also fairly consistently expressed a student-centered view of learning during TBI interviews, expressing that student interactions and active engagement is a sign that learning is occurring in the classroom. During the informal reflection interview, Jamie noted an increased level of student engagement when using the new student-centered practice. “My favorite thing I think...I liked the fact the students were more engaged throughout the semester than I’ve had before, comparing the old way of teaching and the new.” By changing to a student-centered practice, Jamie was able to see positive student outcomes that better aligned with her beliefs about when learning is occurring.

As discussed above, Jamie’s traditional beliefs about when to move on to a new topic would affect the implementation of some lessons or student activities for fear of straying from the syllabus and not covering all the material. Jamie stated during the informal reflection that “I was kind of nervous about the in-class activities, you can tell because I was nervous about how much time they were taking.” While teaching the revised course however, we did reorganize the syllabus schedule to spend an extra day on a topic the students were struggling with as indicated by formative assessments. In an attempt to get Jamie to recall this experience, a probe question was asked about whether Jamie had ever strayed from the syllabus based on formative assessment of the students. The response illustrates how entrenched Jamie’s traditional view about this question is, completely ignoring the student component and providing a very teacher-centered answer: “I think more so than straying from the syllabus, there were a couple times when I didn’t get through all the material in one lecture so I spilled it over into the next lecture and then cut back on a new topic.” Jamie’s unwavering views on this question demonstrate the value of monitoring an instructor’s teaching beliefs during professional development or coaching. Over a longer term, this process could be modified to address deep seated traditional beliefs that would hinder an instructor’s transition to reformed teaching.

Jamie's change in score on the BARSTL survey (figure 3.4) was not as pronounced as on the TBI results. Sampson et al. (2013) suggest that BARSTL scores should not be used to characterize teacher's beliefs based on ranges of scores, but totals can provide a relative position for a teacher's views on science teaching and learning. Looking at responses to individual items that have changed can also be insightful. The shift that Jamie made from 'disagree' to 'agree' on items #9, 17, and 24 from pre- to mid-course were likely influenced by the reformed teaching practices utilized. These items deal with student exploration before instructions, student talk in classrooms, and student led investigations. Classes 4 & 5, which received RTOP score of 59 and 57 respectively, may have influenced this change early on in the course. During these two class periods, samples were brought in and set up around the classroom. Students worked in groups, moved around the classroom to the different stations, studied the samples and answered questions on a provided worksheet. In one class they explored the samples before instruction and in the other they did so after instruction. Jamie and the PI moved around the classroom to assist the students. These types of activities may have influenced Jamie's shift from 'agree' to 'strongly agree' on item #13 as well.

The activity that was used during class 13 that scored a 74 on the RTOP may have influenced Jamie's shift from 'strongly agree' to 'agree' on item #4 of the BARSTL. This item states "Students are more likely to understand a scientific concept if the teacher explains the concept in a way that is clear and easy to understand." Since the concept taught in this class was one that Jamie was not entirely comfortable teaching, the highly student-centered activity used during that class may have been effective at demonstrating that student understanding is not reliant on teacher explanation.

Research Question #4: How would students respond to the reformed teaching strategies as part of their learning experience? As discussed above, it was not feasible to measure student learning gains under the new iteration of the course. As an alternative method to capture student response to the teaching strategies used in the revised course, a Group Instructional Feedback Technique (GIFT) survey was also administered halfway through the semester. Jamie often expressed curiosity about what the students thought of the way the course was being taught, and the GIFT survey provided some insight. The most

common response that students gave regarding what the instructor did to help them learn was the in-class activities (conceptests and worksheets). This demonstrated that students are receptive to reformed teaching strategies and value being active participants in the learning process. Conversely, the most commonly cited impediment to learning was that Jamie lectured too quickly and slowing down was the most cited change that would improve learning. Here students seem to be expressing views opposing a teacher-centered classroom, where the pace is set by the instructor with no input from students or opportunities for their learning to be formatively assessed.

Effectiveness of the Situated Instructional Coaching model: This research utilized a model for professional development that occurred in the classroom and involved collaboration with a reformed teaching coach, in this case a geoscience education graduate student. The model incorporates all three of the strategies that make up successful programs for changing instructional practice according to the NRC (2012): 1) sustained, focused efforts, lasting 4 weeks, one semester, or longer; 2) feedback on instructional practice 3) a deliberate focus on changing faculty conceptions about teaching and learning. The situated instructional coaching model tested was sustained, lasted an entire semester, and focused on revising a single course using a structured model (ICD model; Fink 2009). Second, providing feedback on instructional practice was possible by having a collaborator who assisted with the revisions and attended almost every class. Finally, the main objective of this research was to examine any change in the instructor's beliefs about teaching and learning as a result of the experience. It is recommended that future use of such a model incorporate an assessment and monitoring of the instructor's teaching beliefs.

The situated instructional coaching model can also aide instructors in overcoming the commonly cited barriers to changing their instructional practice. Having a collaborator who can aid in revisions can significantly reduce the time burden of creating objectives, activities, feedback, and assessments. Since training is specific to the course and occurring in the classroom, the instructor is not investing time to attend training workshops, listen to talks, or read the literature. Training is occurring during their normal teaching responsibilities, with feedback and reflection provided immediately by the presence of a coach. The observation

and feedback provided by the coach also ensures that implementation is effective and positive student outcomes are realized.

This case study suggests that the situated instructional coaching model can be successful in promoting change in an instructor's teaching practice and beliefs. The study is not without its limitations. No data were available from prior iterations of the course regarding instructional practice or student performance. Jamie reported having a lecture dominated, traditional instructional style, but no RTOP data from prior iterations of the course are available to confirm. While student performance data were also not available, the revised course utilized research-based strategies that have been shown to promote student learning (e.g. McConnell et al., 2003; Knight and Wood, 2005; Kortz et al., 2008). Other limitations to the use of this model may also exist. The PI and Jamie had an amicable relationship, and Jamie was comfortable with the daily observation in the classroom. Not all instructors may be comfortable with having a coach who is observing them daily in class. Finding a qualified collaborator may present another challenge. Not all departments have a discipline based education research group, however collaboration could occur with a coach in an education department (Bailey and Nagamine, 2012), a faculty peer with established reformed teaching practices could serve as the coach, or with proper institutional support an education specialist can be hired (Wieman et al., 2013).

Future work on the use of a situated instructional coaching model would involve looking at the long term impact of the experience. Does the instructor continue to use the reform-based changes that were implemented in future iterations of a course? Will the instructor apply the skills that they have learned concerning course design and reformed teaching to other courses or to further refine the revised course? This study only had one subject, so it would be of interest to see if using the model produces similar results, especially concerning change in beliefs. Similar collaborative development models have seen changes in belief (Henderson et al., 2009; Bailey and Nagamine, 2012), but none have used the TBI. The purpose of this research was to see the impact of situated instructional coaching on the instructor's beliefs, and none of the TBI interviews were coded until after the semester was over. It would be interesting to incorporate periodic beliefs monitoring as a way to tailor

the instructional change process in order to encourage further shifts toward student-centered beliefs. As seen in this research study and others (Brickhouse, 1990; Cronin-Jones, 1991; Roehrig and Kruse, 2005), beliefs impact the amount and effectiveness of change in practice. Successfully reforming undergraduate STEM education will require changing faculty beliefs about teaching and learning.

CHAPTER 4: CONCLUSIONS

The case studies presented in this research investigated two methods of reforming undergraduate geoscience education. The first looked at the effect that increasing the inquiry level in a geologic time lab would have on student performance on assessments related to the timing and scale of events in Earth's history. It was found that students in the revised higher inquiry labs significantly outperformed students in the original lab on an end of semester assessment. These results demonstrate that even minor revisions in the amount of inquiry within undergraduate labs can significantly increase student understanding of concepts as evidenced by performance on summative assessments.

The second case study presented a new situated instructional coaching model for enacting instructional change within undergraduate geoscience lecture classes. The model serves as an alternative to the normal dissemination methods of reformed teaching practices such as papers, talks, seminars, and workshops. Under the situated instructional coaching model, a geoscience education graduate student assisted a faculty member in revising a traditional lecture-based introductory class to incorporate reformed teaching practices. As a coach, the PI assisted Jamie in creating new lessons and material for the revised course, training in the use of reformed teaching strategies, and provided feedback on implementation. As a result of the experience, Jamie was able to implement reformed lessons, learned to design reformed lessons, and moved toward more student-centered beliefs about teaching and learning. Students also valued being active participants in the learning process. This model shows promise in helping faculty overcome common barriers to instructional reform, ensuring effective implementation of reformed teaching strategies, and promoting belief change. Practices follow beliefs, so moving faculty toward more student-centered beliefs about teaching and learning is likely the most important step toward revising the practices of undergraduate STEM educators.

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APPENDICES

Appendix A: Original Geologic Time Lab

Lab 7: Geologic Time

Pre-lab Activity: Geologic Time so far... (4 pts). Due at the beginning of lab

Geologic time involves the ordering of events and the determination of how long ago they occurred. Before we start the lab, take a few minutes to reflect on what you have learned about the history of Earth so far in the class.

1. In the space below, make a list of as many geologic phenomena or events as you can and place them in order from the most recent (near top of space) to the farthest back in time (bottom of page). It is not necessary to know when all these events occurred, just that their relative order (that is, if they were before or after some of the other events). We have included two examples to get you started.

Most of the Northern Hemisphere was covered by an ice sheet during the last Ice Age.

The supercontinent Pangaea formed.

Name (print and sign): _____

In this lab we will investigate the vast intervals of time in which geologists work. The geologic record, as visible in rocks, is a natural work of art that can tell much about the events that occurred in a certain region and even what organisms lived there. It's just a matter of knowing how to interpret the clues.

First, in a section on relative time, we will explain how early geologists unravel the sequence of events that gave us our present Earth. A section describing the geologic timescale then reviews the history of Earth, especially the major changes in the biosphere over the last half-billion years. Finally, we will explore the concept of numerical time as we examine how scientists determine the ages of geologic features events and estimate the age of Earth.

Objectives: When you have completed this lab you should be able to:

1. Apply the principles of superposition, original horizontality, cross cutting relationships and inclusions to unravel the sequence in which rock units were formed.
2. Draw a diagram that accurately summarizes a simplified geologic history of a region.
3. Create a metaphor for geologic time that shows the relative order and timing of key events in Earth history.
4. Determine the relationship between radioactive decay (half lives, parent and daughter isotopes) and the ages of rocks.

Materials:

3D Structure models
Blank sheets of paper
Graph paper
White boards and pens

Earth History and Relative Time

Relative Time

The study of **relative time** involves placing events in the order in which they occurred. In the context of geology, it means describing the order or sequence of geologic events. There are some basic rules we can apply when analyzing sequences of rocks:

- **Rule #1: Principle of Original Horizontality** - Rock layers that are deposited in water must have originally been horizontal. A consequence of this principle is that sedimentary rocks that are no longer horizontal must have undergone an episode of deformation following their formation. For example, sedimentary layers are often tilted during the uplift associated with mountain formation.
- **Rule #2: Principle of Superposition** - In a series of sedimentary rock layers that are not deformed or are only lightly deformed, the rocks at the bottom of the stack are the oldest and the rocks at the top are the youngest. The same principle can be extended to many forms of volcanic igneous rocks. Volcanic eruptions can produce layers from lava flows or when ash and other debris fall back to Earth.
- **Rule #3: Principle of cross-cutting relationships** - older rocks may be cut by younger rocks (e.g., igneous pluton) or other geologic features (e.g., faults). When magma intrudes into a rock, it must be younger than the rock it cuts across, or when a fault cuts across rock layers, it must be younger than the layers.
- **Rule #4: Principle of Inclusions** - A variation on the cross cutting theme is that younger rock units may incorporate pieces of older rocks. For example, chunks of surrounding rock may collapse into a mass of magma as the molten rock forces its way upward through the crust. These preserved chunks of rock are known as inclusions. The principle of inclusions can be applied to identify older pieces of rock surrounded by younger igneous rocks.

Erosion occurs when rocks are uplifted to Earth's surface. This erosional surface is called an **unconformity** and represents a time when rocks were not being deposited and/or were undergoing erosion. The unconformity surface is a physical boundary between the two sections of rocks that represents a gap in time. The rocks immediately over the unconformity surface often contain coarse grained clastic sedimentary rocks formed by erosion. Three types of unconformity are recognized:

- **Angular unconformity** – sedimentary rocks are deposited over underlying tilted layers.
- **Nonconformity** – sedimentary rocks are deposited over igneous or metamorphic rocks.
- **Disconformity** – sedimentary rocks are parallel above and below the unconformity surface.

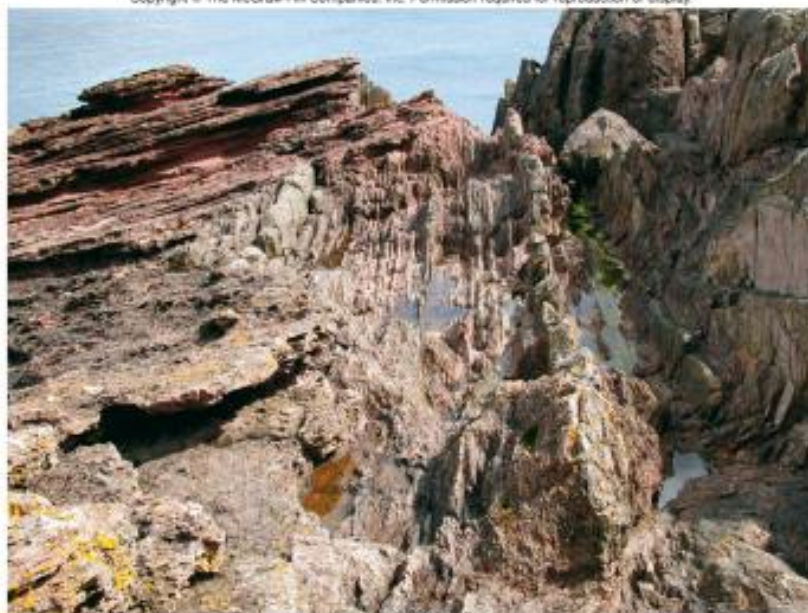
The earth history of Siccar Point, Scotland

In the late 18th century, Scottish scientist James Hutton noted that the landscape of his farmlands remained unchanged with the passage of time. From this modest observation, he deduced two significant hypotheses. First, he suggested **that the same slow-acting geologic processes that operate today must have operated in the past**; therefore, it must take a very long time for processes to produce any significant change in the shape of Earth's surface. Second, Hutton noted that **all land should be worn flat unless some process acts to renew the landscape by forming new mountains**, which then renews the slow cycle of destruction.

Hutton set out to find some examples of rocks that illustrated this idea of cyclical change. He found his evidence at an outcrop of rocks along the east coast of Scotland at a location known as Siccar Point (see image). Here, he discovered nearly flat rocks overlying nearly vertical layers.

He hypothesized that:

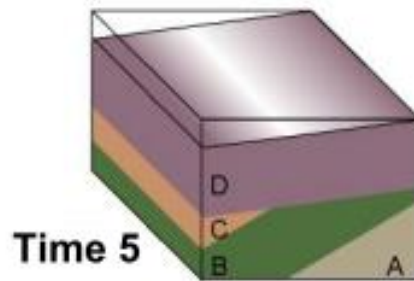
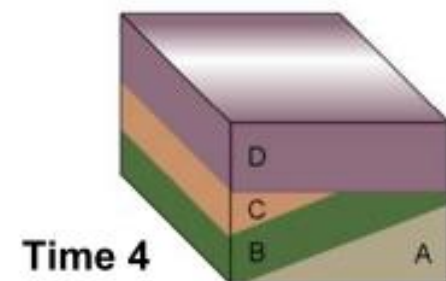
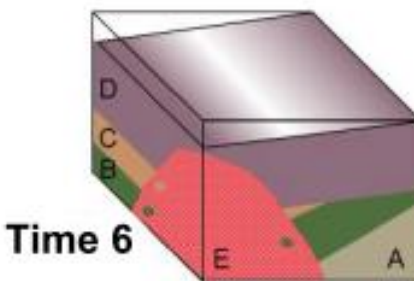
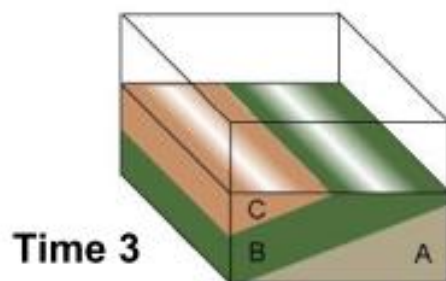
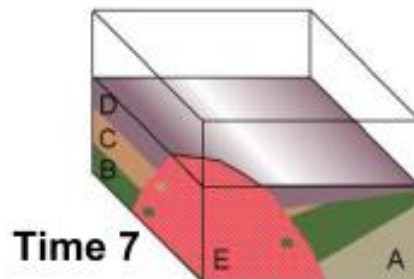
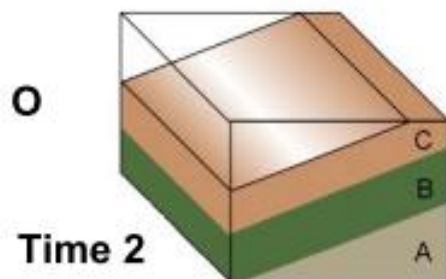
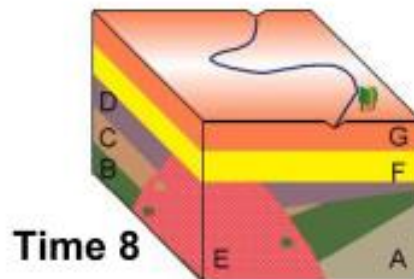
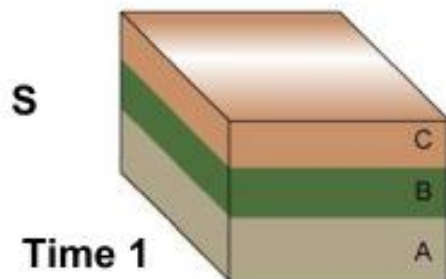
- a) The lower layers of rock formed first (superposition) as flat layers (original horizontality).
- b) The layers were later uplifted to the surface and tilted (original horizontality).
- c) The tilted layers were then worn down by erosion (forming an unconformity surface).
- d) The eroded layers were submerged below water and buried beneath new horizontal deposits of sediment (superposition, cross-cutting).



Analysis: Identify indicators of four principles

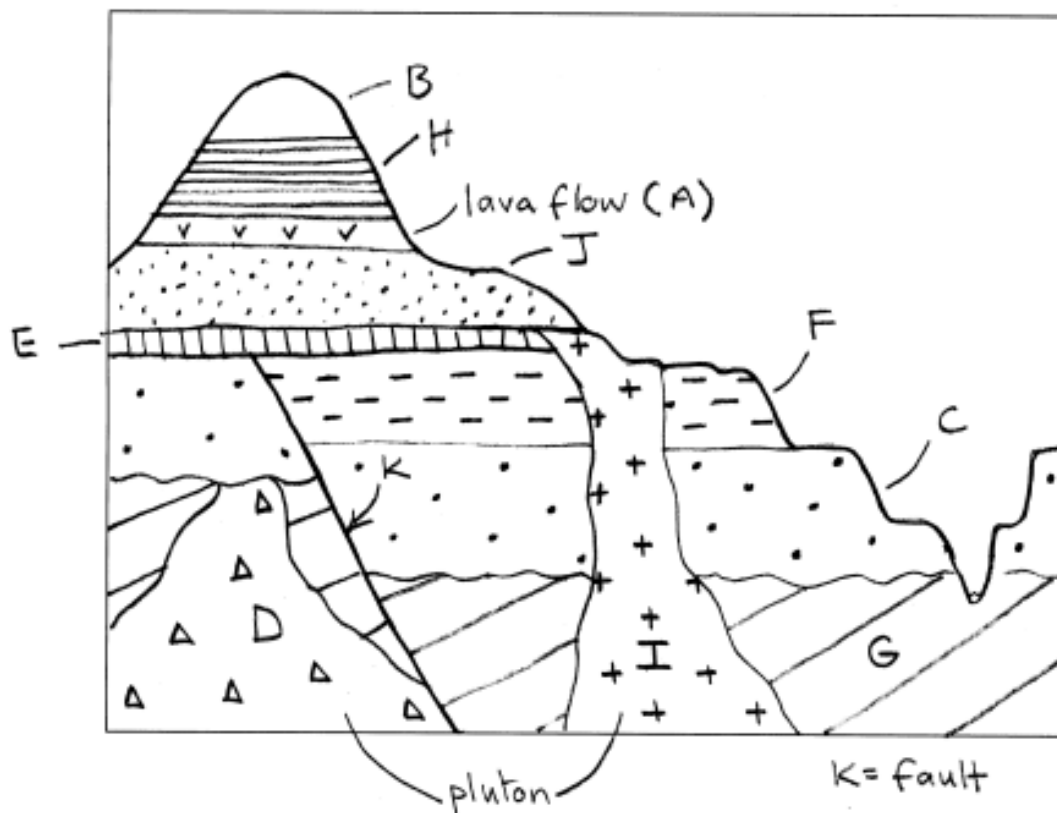
Label the diagrams below to show examples of the four principles described above. (2 pts)

- Place an S beside the figure to indicate superposition, O for original horizontality, C for cross cutting, and I for inclusions. Only use the letters for the first occurrence of a feature. Some figures will have no labels. The first two have been completed.
- Label specific examples of unconformities (angular, nonconformity, disconformity) if present.



Analysis: Use the principles to determine a sequence of events (6 pts)

1. Interpret the sequence of events in the relative time diagram below. Place the rocks in the correct sequence from youngest to oldest.

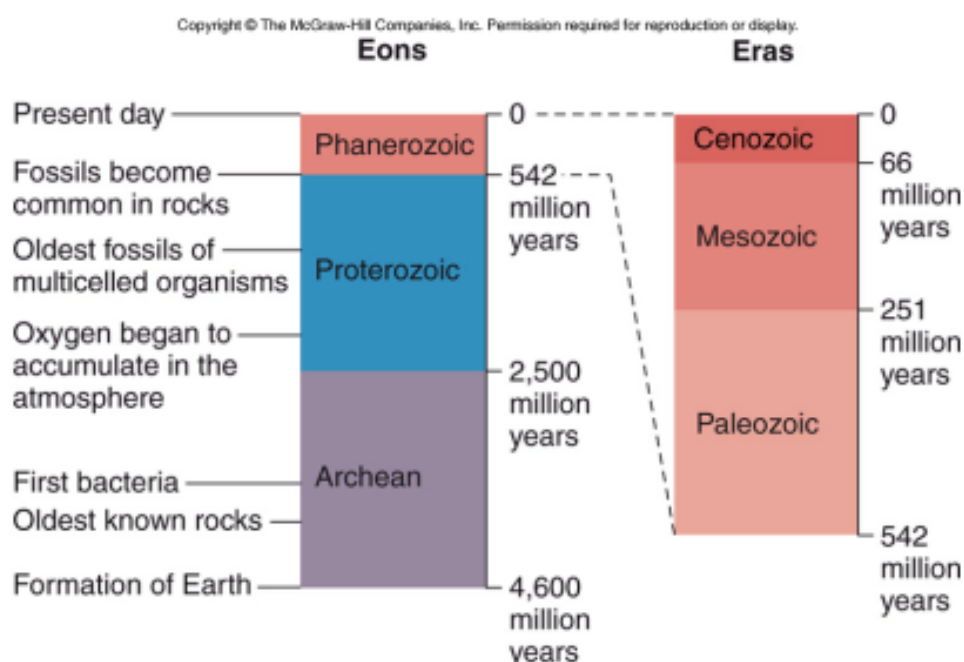


- | | |
|----------|-----|
| Youngest | 11. |
| | 10. |
| | 9. |
| | 8. |
| | 7. |
| | 6. |
| | 5. |
| | 4. |
| | 3. |
| | 2. |
| Oldest | 1. |

Analysis: Use the principles to create a sequence of events [6 pts]

2. Draw a labeled diagram on a whiteboard with at least six units of rock. Your diagram should reflect a geologic history that includes, in no particular order:
 - the deposition of at least two sets of formations of sedimentary rocks formed at different times
 - an episode of deformation when rocks were tilted and/or folded and/or faulted
 - at least one interval of erosion represented by an unconformity (that is not the present day land surface)
 - a record of volcanic activity indicated by a lava flow or a layer of volcanic ash (tephra)
 - the formation of the plutonic igneous rock, granite, that is younger than some rocks but older than others.
- a. On a separate sheet of paper, list the events that represent the geologic history of your diagram. Write the events in order from oldest to youngest.
- b. Swap a diagram with a neighboring group. List the events that represent the geologic history of their diagram.
- c. Discuss your interpretations of the other team's diagram with them and they will discuss your diagram with your group. Adjust your diagram accordingly and sketch it in the space below.

Earth's past is divided into three big chunks of time known as eons. Eons are the largest intervals of the timescale, each over 500 million years long, and they mark major changes in the earth system. The oldest known rocks (~4.2 billion years old) were formed during the early Archean eon. This used to be called the Hadean eon and some people still use that term to represent the earliest part of Earth's history from its initial molten state 4.6 billion years ago until the first rocks formed. Evidence from later in the Archean eon indicates that the first continents formed and primitive life emerged in the form of the first bacteria. About 2 billion years ago, during the Proterozoic eon ("earlier life"), oxygen began to accumulate in the atmosphere in greater quantities than before (as evidenced by oxidized minerals in ancient rocks), and life evolved beyond primitive bacteria.



The beginning of the most recent eon, the Phanerozoic ("life revealed"), marks the break between younger rocks that contain abundant fossils formed from organisms with shells and hard skeletons, and older rocks in which fossils are rare. The Phanerozoic eon represents just the last 12% of geologic time. Life on Earth has been repeatedly affected by **mass extinction events that resulted in the death of large numbers of species**. So dramatic were these events that the types of fossils formed prior to the extinction event are substantially different from those found in rocks deposited following the extinction event. These contrasts in the fossil record were used to divide the Phanerozoic eon into **three shorter eras (Paleozoic, Mesozoic, and Cenozoic; see table)**. Paleozoic is derived from the Greek for "ancient life," Mesozoic means "middle life," and Cenozoic represents "new life." Each of the eras is further subdivided into shorter time intervals known as periods (see table).

The Geologic Timescale

ERA	PERIOD	REMARKS	Myrs
Cenozoic	Neogene	Large ice sheets centered on Earth's poles. Large mammals abundant (e.g., mastodons, mammoths); earliest human ancestors appeared.	23–0
	Tertiary* Paleogene	Age of Mammals began. First large mammals on land and in the ocean (e.g., whales, elephants, horses, bears); radiation of echinoids.	66–23
Mesozoic	Cretaceous	Dinosaurs dominated the earth. First grasses and flowering plants appeared; dinosaurs wiped out by an extinction event at the end of the period; ammonites abundant.	145–66
	Jurassic	Atlantic Ocean began to form. First birds appeared; dinosaurs and flying reptiles (pterosaurs) common.	200–145
	Triassic	Pangaea began to split apart. Reptiles dominated the earth; earliest mammals and dinosaurs appeared; first conifers; modern corals developed.	251–200
Paleozoic	Permian	Much marine life was wiped out in most massive extinction known at the end of the Permian.	299–251
	Pennsylvanian** (Late Carboniferous)	Appalachian Mountains formed when North America collided with Africa. Insects and early reptiles on land; first evergreen trees appeared, earliest forests.	318–299
	Mississippian** (Early Carboniferous)	Shallow tropical oceans covered much of the interior of North America. Marine fossils in limestone common.	360–318
	Devonian	Age of Fishes. First land vertebrate animals (tetrapods; amphibians); first seed plants, trees, and forests. Insects on land as well.	416–360
	Silurian	First primitive plants occur on land (ferns, mosses). First fish with jaws appeared; much of North America was under a shallow tropical sea with abundant reefs.	444–416
	Ordovician	North America was near the equator. Abundant marine life.	488–444
	Cambrian	Explosion of organisms with hard skeletons (that can be easily preserved as fossils) occurred at beginning of Cambrian; trilobites flourished.	542–488
Precambrian		Fossils rare in Precambrian rocks. Soft-bodied organisms present in the youngest Precambrian rocks; dominated by single-celled life.	4,600–542

* Authorities have recently recommended that the name Tertiary be replaced by two new periods, the Neogene and Paleogene. It will take several years before this change is widely accepted.

** These periods are used widely in North America, but are combined to form the Carboniferous period internationally.

Ancient Leaves and Insect Extinctions

3. Read the following article and then answer the questions that follow. [6 pts]

When a 6-mile-wide asteroid slammed into Earth 65 million years ago, it wiped out the dinosaurs, about 80% of the world's plant species, and all animals bigger than a cat. But what happened to the bugs?

It's been tough for scientists to determine how the insects fared because bugs rarely leave behind fossils. But a Denver paleontologist and his Smithsonian Institution colleagues found a way around the problem: By studying insect damage etched into thousands of fossil leaves, they determined that many plant-eating bugs perished in the big impact.

"These little insects are leaving their calling cards on the fossil leaves, and we have an excellent fossil record of leaves," said Kirk Johnson, curator of paleontology at the Denver Museum of Nature & Science. "So by looking at the insect damage on the leaves before and after the dinosaur extinctions, we can make a pretty good educated guess of what happened to the insects."

Johnson and his collaborators estimate that 55% to 60% of plant-eating insects were exterminated. Over the past 20 years, Johnson has collected 13,441 plant fossils from quarries in southwestern North Dakota. When the asteroid hit Mexico's Yucatan Peninsula, it threw up clouds of dust that traveled around the globe. Johnson pulled the fossils from rock layers directly above and below those sediments. At the time, southwestern North Dakota was a warm, forested plain with lots of broad-leafed trees.

Some leaves, now stored at the Denver museum and at Yale University, are up to a foot long. Individual leaf veins are visible, as are the diagnostic chomp marks, tunnels, and holes left by prehistoric beetles, grasshoppers, butterflies, caterpillars and moths. Some insects are specialists, relying on a single species of plant for sustenance; others are generalists that feed on several plant types. By analyzing insect-damaged leaves before and after the impact, the researchers determined that the generalists survived, while 70% of the specialists did not.

Source: Rocky Mountain News (Denver, CO), February 22, 2002

- a. What was the question being investigated by the scientists?

- b. What observations did the scientists make during their investigations?

- c. What was the principal conclusion of their research?

Geological Time Metaphor: Football Field

All of geologic time is proportional to the length of a football field (100 yards).
Earth would have formed at the opposing team's goal line (100 yards) and present day would represent the home team's goal line (0 yards).

Metaphor Equation:

$$\text{Metaphor value} = (\text{Years before present} / \text{Age of Earth}) \times \text{Metaphor maximum}$$

Example:

Oldest fossil bacteria = 3500 million years old

Age of Earth = 4600 million years

Metaphor maximum = 100 yards

Metaphor value = $(3,500,000,000 / 4,600,000,000) \times 100 = 76$ yards

Key metaphor dimensions:

100 yards = 4600 million years

10 yards = 460 million years

1 foot = 15.3 million years

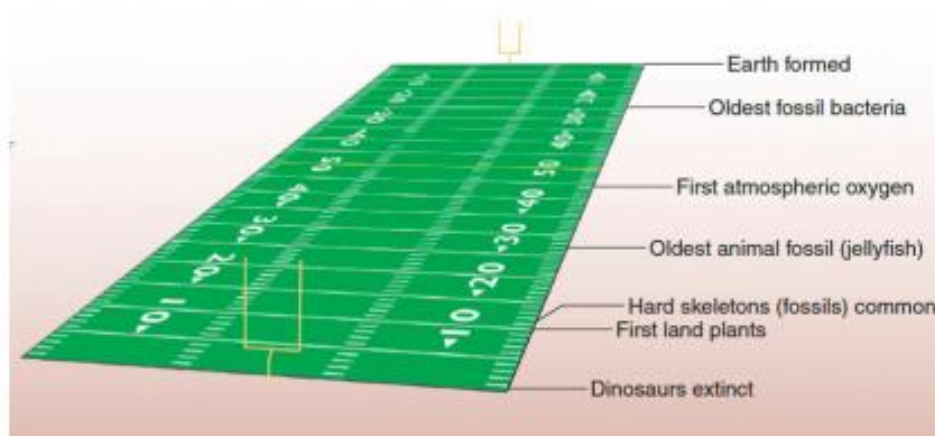
1 inch = 1.3 million year

1 yard = 46 million year

Distance from home goal line	Time (million years)	Event
76 yards	3500	Oldest fossil bacteria
26 yards	1200	Oldest known animal fossil (jellyfish)
12 yards	542	Hard skeletons become common (fossils)
10 yards	458	First land plants (ferns, mosses)
	251	Widespread extinction ends Paleozoic Era
1.4 yards	65	Dinosaurs become extinct
0.00036 inches	0.00051	Columbus landed, 1492

Calculate the yardage of the extinction at the end of the Paleozoic Era and complete the table above and label the figure below.

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Geological Time Metaphor

Analysis: The geologic time scale metaphor [6 pts]

4. We are going to create a class metaphor for geological time using 46 feet of adding machine tape to represent the 4.6 billion years of Earth's history. Your instructor will assign each person in your group a significant geological event from the table on p. 8, as well as some of those identified in the pre-class activity. In the space below, calculate how many feet and inches each of your events takes place from the end of the tape.

Event:

Length:

Event:

Length:

Event:

Length:

Event:

Length:

When you are out in the hall, you will be asked to explain your relative position using the events around you.

Radioactive Decay

Atoms of the same element with different numbers of neutrons are called **isotopes**. For example, potassium has three isotopes with 20, 21, or 22 neutrons (figure 8.21). Each has 19 protons (atomic number), but its mass number may be 39, 40, or 41, depending on the number of neutrons. The positively charged protons in a nucleus repel each other tending to make the nucleus unstable. When enough neutrons are present, these forces are minimized. When a nucleus is unstable, it may spontaneously change to a more stable form through the process of radioactive decay. **Radioactive decay occurs when an unstable isotope changes to a new element during a change in the number of neutrons or protons.**

Just as parents produce children, **the unstable original isotope is termed the parent isotope, while the product of the decay is the daughter atom.** For example, parent ^{40}K decays to daughter ^{40}Ar (argon) or ^{40}Ca (calcium), depending upon whether protons are lost or gained, respectively. Radioactive decay starts and daughter atoms begin to accumulate in rocks as soon as an element forms. New minerals form when magma solidifies to form igneous rocks or when changing temperature results in the formation of metamorphic rocks.

Many decades of observations have shown that radioactive decay of specific isotopes occurs at a constant rate regardless of the physical or chemical conditions. By keeping track of the relative amounts of isotopes in individual minerals, we can calculate an age for the rock containing that mineral. Let's see how that is done.

The half-life of an isotope is the time taken for half of the parent isotopes to convert to daughter atoms. When a mineral originally forms, prior to decay, 100% of the parent isotope exists because radioactive decay has yet to occur, assuming no daughter element was present at the time of formation. As time passes, the amount of the parent isotope decreases, and the quantity of the daughter atom increases. After one half-life, 50% of the parent remains, and the other 50% of the original atoms are converted to daughter atoms (table). After two half-lives, the number of parent isotopes is again halved (25%), and the number of daughter atoms increases by an equivalent amount (to 75%).

Analysis: Half-life Exercise [7 pts]

5. Take the piece of paper provided, tear it in half, and set one half aside. Keep doing this every 10 seconds until you cannot tear it in half any more.

a. How small was the final piece in comparison to the piece you began with? (circle) (1 pt)

$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{1}{128}$	$\frac{1}{256}$	$\frac{1}{512}$	$\frac{1}{1024}$	$\frac{1}{2048}$	$\frac{1}{4096}$
50%	25%	12.5%	6.25%	3.125%	1.5625%	0.78125%	0.391%	0.195%	0.098%	0.049%	0.024%

b. This exercise is analogous to radioactive decay. The paper is a population of radioactive isotopes. The half-life of the paper is 10 seconds. How many "half lives" did your "sample" experience before it became too _____ small to be divided again?

c. Complete the table below to identify the proportions of parent and daughter isotopes that would be formed for an equivalent number of half lives. (2 pts)

Proportion of Parent and Daughter Isotopes as a Result of Radioactive Decay		
Number of Half-lives	Parent Isotopes (% total isotopes)	Daughter Isotopes (% total isotopes)
0	100	0
$1/64$	98.9	1.1
$1/32$	97.9	2.1
$1/16$	95.8	4.2
$1/8$	91.7	8.3
$1/4$	84.1	15.9
$1/2$	70.7	29.3
1	50	50
2	25	75
3	12.5	87.5
4	6.25	93.75
5	3.125	96.875
6		
7		
8		
9		99.805
10		99.9024
11		99.9512
12		99.9756

d. Plot a graph of half lives vs. proportion of parent and daughter atoms. (2 pts)

The relative proportion (ratio) of parent isotopes and daughter atoms can be used to determine how many half-lives have passed since the formation of the mineral that contained the radioactive isotopes (table). The half-lives for several of the most common radioactive isotopes are measured in millions or billions of years (table). Isotopes with half-lives measured in billions or hundreds of millions of years can be used to determine the ages of the oldest rocks in the world.

Let us look at an example of how dating can be done using half-lives: The oldest calculated date for some rocks in northwestern Canada is approximately 4 billion years. The half-life for ^{238}U isotopes is 4.5 billion years and therefore these isotopes would have experienced a little less than one half-life in a 4-billion-year-old rock (4,000 million years). Such rocks should have a few more ^{238}U parent isotopes (55%) than ^{206}Pb daughter atoms (45%).

In comparison, the half-life for ^{235}U to ^{207}Pb decay is 0.7 billion years; ^{235}U isotopes in a 4-billion-year-old rock would have experienced nearly six half-lives and would have approximately 2% of the ^{235}U parent isotope remaining and 98% of ^{207}Pb (see table).

Half lives	^{235}U %	^{207}Pb %	Age
0	100	0	0
1	50	50	704
2	25	75	1408
3	12.5	87.5	2112
4	6.25	93.75	2818
5	3.125	96.875	3520
6	1.5625	98.4375	4224

Not all radioactive isotopes decay over such long periods. The carbon isotope, ^{14}C , experiences a half-life every 5,730 years. ^{14}C is used to date archeological artifacts such as cloth fragments from Egyptian pyramids and organic material (e.g., bone, charcoal) found in some very young rocks (younger than 60,000 years of age).

Half-lives for Common Radioactive Isotopes

Parent Isotope	Daughter Atom	Length of Half-life	# Half-lives gone through in 1 billion years?
Rubidium 87 (^{87}Rb)	Strontium 87 (^{87}Sr)	48.8 billion years	
Uranium 238 (^{238}U)	Lead 206 (^{206}Pb)	4.5 billion years	
Potassium 40 (^{40}K)	Argon 40 (^{40}Ar)	1.25 billion years	
Uranium 235 (^{235}U)	Lead 207 (^{207}Pb)	704 million years	
Beryllium 10 (^{10}Be)	Boron 10 (^{10}B)	1.5 million years	
Carbon 14 (^{14}C)	Nitrogen 14 (^{14}N)	5,730 years	

- e. Imagine that you were analyzing a rock that was approximately 1000 million (1 billion) years old. Use labeled arrows to indicate on the graph the relative proportions of parent and daughter isotopes for each of the radioactive isotopes listed in the table above. You can fill in the column in the chart above to help get you started. (2 pts)

Analysis: Calculating the Age of North Carolina Rocks [8 pts]

6. Answer the questions that follow.

- a. If a rock started with 1,000 atoms of a parent but now contains 250 parent atoms, how many half lives have passed?
 a) 0.25 half lives c) 1 half life
 b) 0.5 half lives d) 2 half lives
- b. The half life of radioactive isotope X is 2 billion years. Approximately how much of the parent isotope and its daughter product is present in a rock that is 4.5 billion years old?
 a) 79% parent & 21% daughter c) 47% parent & 53% daughter
 b) 53% parent & 47% daughter d) 21% parent & 79% daughter
- c. Using some of the data in the tables of pages 13 and 15, complete the table below to estimate the approximate relative proportions of parent and daughter atoms in the oldest dated rock in North Carolina which has been determined to be 1.8 billion years old.

Parent	# of half-lives	% Parent isotope	Daughter	% Daughter isotope
Uranium 238 (^{238}U)			Lead 206 (^{206}Pb)	
Uranium 235 (^{235}U)			Lead 207 (^{207}Pb)	
Rubidium 87 (^{87}Rb)			Strontium 87 (^{87}Sr)	
Potassium 40 (^{40}K)			Argon 40 (^{40}Ar)	

- d. C^{14} can only be used when we have organic materials which are not present in most rocks. If we were to have organic material in a 1.8 billion year old rock, how many half lives would have passed for the C^{14} isotopes?
- e. Could scientists use carbon dating techniques to determine an age for the oldest rocks in North Carolina? Explain.
- f. Could scientists use fossils to date the oldest rocks in North Carolina? Explain.
- g. Which of the radioactive elements in the table, "Half-lives for Common Radioactive Isotopes" would be the best to use to provide an accurate date on rocks that were approximately 10 million years old?
 a) ^{10}Be b) ^{87}Rb c) ^{14}C

Name (print and sign): _____

In this lab we will investigate the vast intervals of time in which geologists work. The geologic record, as visible in rocks, is a natural work of art that can tell much about the events that occurred in a certain region and even what organisms lived there. It's just a matter of knowing how to interpret the clues.

First, we will explore the geologic timescale using fossils and a measuring tape metaphor to create our own timeline. In a section on relative time, we will explain how early geologists unravel the sequence of events that gave us our present Earth. Finally, we will explore the concept of numerical time as we examine how scientists determine the ages of geologic features and estimate the age of Earth.

Objectives: When you have completed this lab you should be able to:

1. Apply the principles of superposition, original horizontality, cross cutting relationships and inclusions to unravel the sequence in which rock units were formed.
2. Draw a diagram that accurately summarizes a simplified geologic history of a region.
3. Create a metaphor for geologic time that shows the relative order and timing of key events in Earth history.
4. Determine the relationship between radioactive decay (half lives, parent and daughter isotopes) and the ages of rocks.

Materials:

Measuring Tape

Box of geologic artifacts

White boards and pens

Blank sheets of paper

Graph paper

Part I: Exploring Earth's History

Geological Time Metaphor

Analysis: The geologic time scale metaphor [12 pts]

- We are going to create a class metaphor for geological time using 46 feet of measuring tape to represent the 4.6 billion years of Earth's history.
 - How much time does each foot of the measuring tape represent in million years (Ma) (0.5 pt)?
 - Each inch (0.5 pt)?
 - Write and solve an equation to convert 9 ft. 4 in. to time in million years ago (Ma) (1 pt).
- Your instructor will assign each person in your group a significant geological artifact (or two). As a class you will reconstruct the Earth history represented in these artifacts by placing them on the measuring tape timeline in the correct order and at the correct time. (If your artifact is a fossil, you will use the date of first appearance of that organism.) Discuss with those around you to determine the correct sequence of events and evolutionary appearance of organisms. Record your artifact #, your initial placement location, and its age in million years ago (Ma) in the table below (1 pt).

	1 st Artifact	2 nd Artifact
a. Artifact #		
b. Initial artifact placement (ft. & in.)		
c. Million years ago (Ma)		

- Leave your artifact beside the timeline. Your instructor will now tell you the correct placement of your artifact (2 pts).

	1 st Artifact	2 nd Artifact
a. Correct placement (ft. & in.)		
b. Correct age (Ma)		
c. How far off were you? = $ 2.c - 3.b $		

Move your artifact to its correct location and use the completed timeline to answer the questions on the next page.

OPTIONAL: Report your error from 3b. to your instructor who will calculate a class average. You can then see how accurate your timeline was compared to other sections.

PART II: Earth History and Relative Dating

Relative Time

The study of **relative time** involves placing events in the order in which they occurred. In the context of geology, it means describing the order or sequence of geologic events. There are some basic rules we can apply when analyzing sequences of rocks:

- **Rule #1: Principle of Original Horizontality** - Rock layers that are deposited in water must have originally been horizontal. A consequence of this principle is that sedimentary rocks that are no longer horizontal must have undergone an episode of deformation following their formation. For example, sedimentary layers are often tilted during the uplift associated with mountain formation.
- **Rule #2: Principle of Superposition** - In a series of sedimentary rock layers that are not deformed or are only lightly deformed, the rocks at the bottom of the stack are the oldest and the rocks at the top are the youngest. The same principle can be extended to many forms of volcanic igneous rocks. Volcanic eruptions can produce layers from lava flows or when ash and other debris fall back to Earth.
- **Rule #3: Principle of cross-cutting relationships** - older rocks may be cut by younger rocks (e.g., igneous pluton) or other geologic features (e.g., faults). When magma intrudes into a rock, it must be younger than the rock it cuts across, or when a fault cuts across rock layers, it must be younger than the layers.
- **Rule #4: Principle of Inclusions** - A variation on the cross cutting theme is that younger rock units may incorporate pieces of older rocks. For example, chunks of surrounding rock may collapse into a mass of magma as the molten rock forces its way upward through the crust. These preserved chunks of rock are known as inclusions. The principle of inclusions can be applied to identify older pieces of rock surrounded by younger igneous rocks.

Erosion occurs when rocks are uplifted to Earth's surface. This erosional surface is called an **unconformity** and represents a time when rocks were not being deposited and/or were undergoing erosion. The unconformity surface is a physical boundary between the two sections of rocks that represents a gap in time. The rocks immediately over the unconformity surface often contain coarse grained clastic sedimentary rocks formed by erosion. Three types of unconformity are recognized:

- **Angular unconformity** – sedimentary rocks are deposited over underlying tilted layers.
- **Nonconformity** – sedimentary rocks are deposited over igneous or metamorphic rocks.
- **Disconformity** – sedimentary rocks are parallel above and below the unconformity surface.

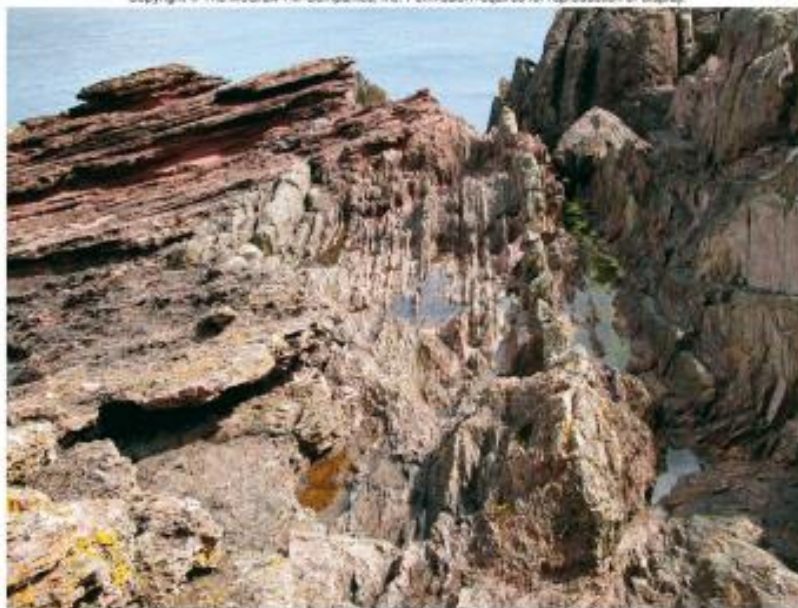
The earth history of Siccar Point, Scotland

In the late 18th century, Scottish scientist James Hutton noted that the landscape of his farmlands remained unchanged with the passage of time. From this modest observation, he deduced two significant hypotheses. First, he suggested **that the same slow-acting geologic processes that operate today must have operated in the past**; therefore, it must take a very long time for processes to produce any significant change in the shape of Earth's surface. Second, Hutton noted that **all land should be worn flat unless some process acts to renew the landscape by forming new mountains**, which then renews the slow cycle of destruction.

Hutton set out to find some examples of rocks that illustrated this idea of cyclical change. He found his evidence at an outcrop of rocks along the east coast of Scotland at a location known as Siccar Point (see image). Here, he discovered nearly flat rocks overlying nearly vertical layers.

He hypothesized that:

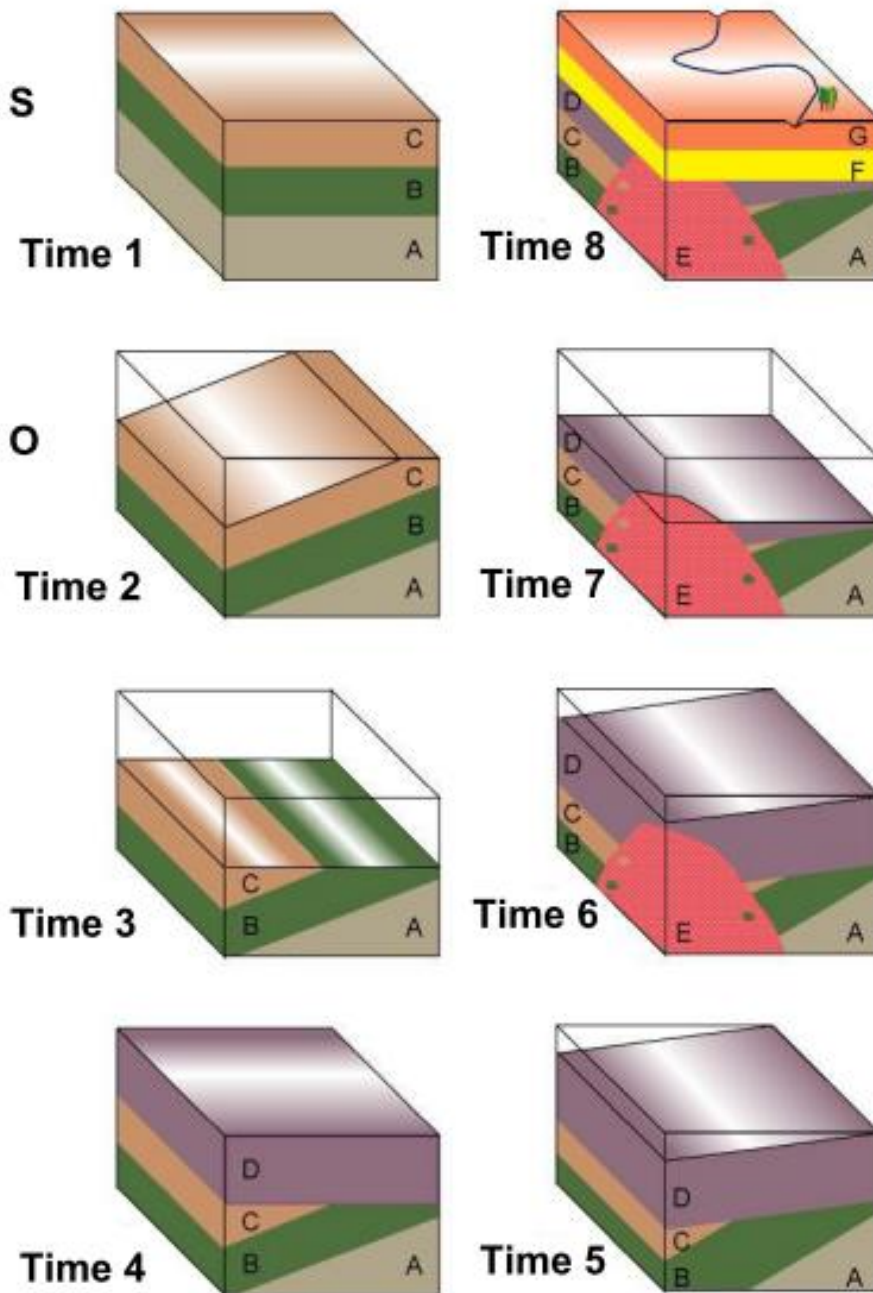
- a) The lower layers of rock formed first (superposition) as flat layers (original horizontality).
- b) The layers were later uplifted to the surface and tilted (original horizontality).
- c) The tilted layers were then worn down by erosion (forming an unconformity surface).
- d) The eroded layers were submerged below water and buried beneath new horizontal deposits of sediment (superposition, cross-cutting).



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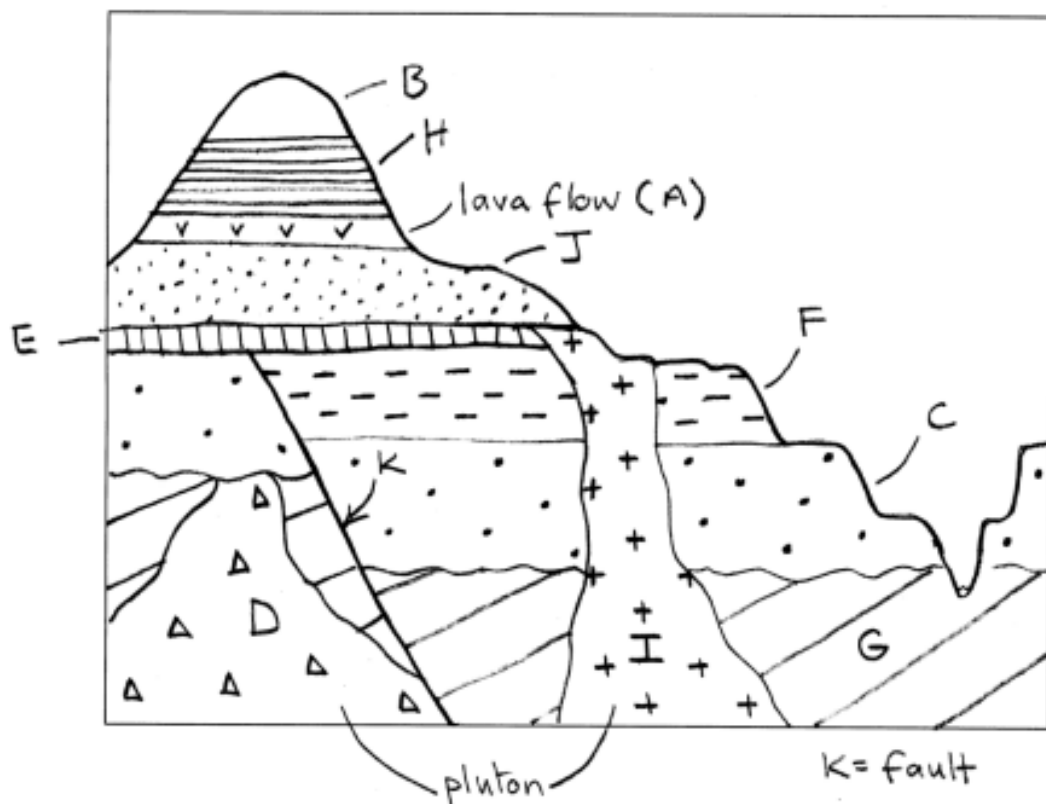
Analysis: Identify indicators of four principles

7. Label the diagrams below to show examples of the four principles described above. (2 pts)
- Place an S beside the figure to indicate superposition, O for original horizontality, C for cross cutting, and I for inclusions. Only use the letters for the first occurrence of a feature. Some figures will have no labels. The first two have been completed.
 - Label specific examples of unconformities (angular, nonconformity, disconformity) if present.



Analysis: Use the principles to determine a sequence of events (6 pts)

8. Interpret the sequence of events in the relative time diagram below. Place the rocks in the correct sequence from youngest to oldest.



- | | |
|----------|-----|
| Youngest | 11. |
| | 10. |
| | 9. |
| | 8. |
| | 7. |
| | 6. |
| | 5. |
| | 4. |
| | 3. |
| | 2. |
| Oldest | 1. |

Analysis: Use the principles to create a sequence of events [6 pts]

9. Draw a labeled diagram on a whiteboard with at least six units of rock. Your diagram should reflect a geologic history that includes, in no particular order:
 - a. the deposition of at least two sets of formations of sedimentary rocks formed at different times
 - b. an episode of deformation when rocks were tilted and/or folded and/or faulted
 - c. at least one interval of erosion represented by an unconformity (that is not the present day land surface)
 - d. a record of volcanic activity indicated by a lava flow or a layer of volcanic ash (tephra)
 - e. the formation of the plutonic igneous rock, granite, that is younger than some rocks but older than others.
- a. On a separate sheet of paper, list the events that represent the geologic history of your diagram. Write the events in order from oldest to youngest.
- b. Swap a diagram with a neighboring group. List the events that represent the geologic history of their diagram.
- c. Discuss your interpretations of the other team's diagram with them and they will discuss your diagram with your group. Adjust your diagram accordingly and sketch it in the space below.

PART III: Absolute Dating

Radioactive Decay

Atoms of the same element with different numbers of neutrons are called **isotopes**. For example, potassium has three isotopes with 20, 21, or 22 neutrons (figure 8.21). Each has 19 protons (atomic number), but its mass number may be 39, 40, or 41, depending on the number of neutrons. The positively charged protons in a nucleus repel each other tending to make the nucleus unstable. When enough neutrons are present, these forces are minimized. When a nucleus is unstable, it may spontaneously change to a more stable form through the process of radioactive decay. **Radioactive decay occurs when an unstable isotope changes to a new element during a change in the number of neutrons or protons.**

Just as parents produce children, **the unstable original isotope is termed the parent isotope, while the product of the decay is the daughter atom.** For example, parent ^{40}K decays to daughter ^{40}Ar (argon) or ^{40}Ca (calcium), depending upon whether protons are lost or gained, respectively. Radioactive decay starts and daughter atoms begin to accumulate in rocks as soon as an element forms. New minerals form when magma solidifies to form igneous rocks or when changing temperature results in the formation of metamorphic rocks.

Many decades of observations have shown that radioactive decay of specific isotopes occurs at a constant rate regardless of the physical or chemical conditions. By keeping track of the relative amounts of isotopes in individual minerals, we can calculate an age for the rock containing that mineral. Let's see how that is done.

The half-life of an isotope is the time taken for half of the parent isotopes to convert to daughter atoms. When a mineral originally forms, prior to decay, 100% of the parent isotope exists because radioactive decay has yet to occur, assuming no daughter element was present at the time of formation. As time passes, the amount of the parent isotope decreases, and the quantity of the daughter atom increases. After one half-life, 50% of the parent remains, and the other 50% of the original atoms are converted to daughter atoms (table). After two half-lives, the number of parent isotopes is again halved (25%), and the number of daughter atoms increases by an equivalent amount (to 75%).

Analysis: Half-life Exercise [7 pts]

10. Take the piece of paper provided, tear it in half, and set one half aside. Keep doing this every 10 seconds until you cannot tear it in half any more.

- a. How small was the final piece in comparison to the piece you began with? (circle) (1 pt)

$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{1}{128}$	$\frac{1}{256}$	$\frac{1}{512}$	$\frac{1}{1024}$	$\frac{1}{2048}$	$\frac{1}{4096}$
50%	25%	12.5%	6.25%	3.125%	1.5625%	0.78125%	0.391%	0.195%	0.098%	0.049%	0.024%

- b. This exercise is analogous to radioactive decay. The paper is a population of radioactive isotopes. The half-life of the paper is 10 seconds. How many "half lives" did your "sample" experience before it became too _____ small to be divided again?

- c. Complete the table below to identify the proportions of parent and daughter isotopes that would be formed for an equivalent number of half lives. (2 pts)

Proportion of Parent and Daughter Isotopes as a Result of Radioactive Decay		
Number of Half-lives	Parent Isotopes (% total isotopes)	Daughter Isotopes (% total isotopes)
0	100	0
$1/64$	98.9	1.1
$1/32$	97.9	2.1
$1/16$	95.8	4.2
$1/8$	91.7	8.3
$1/4$	84.1	15.9
$1/2$	70.7	29.3
1	50	50
2	25	75
3	12.5	87.5
4	6.25	93.75
5	3.125	96.875
6		
7		
8		
9		99.805
10		99.9024
11		99.9512
12		99.9756

- d. Plot a graph of half lives vs. proportion of parent and daughter atoms. (2 pts)

The relative proportion (ratio) of parent isotopes and daughter atoms can be used to determine how many half-lives have passed since the formation of the mineral that contained the radioactive isotopes (table). The half-lives for several of the most common radioactive isotopes are measured in millions or billions of years (table). Isotopes with half-lives measured in billions or hundreds of millions of years can be used to determine the ages of the oldest rocks in the world.

Let us look at an example of how dating can be done using half-lives: The oldest calculated date for some rocks in northwestern Canada is approximately 4 billion years. The half-life for ^{238}U isotopes is 4.5 billion years and therefore these isotopes would have experienced a little less than one half-life in a 4-billion-year-old rock (4,000 million years). Such rocks should have a few more ^{238}U parent isotopes (55%) than ^{206}Pb daughter atoms (45%).

In comparison, the half-life for ^{235}U to ^{207}Pb decay is 0.7 billion years; ^{235}U isotopes in a 4-billion-year-old rock would have experienced nearly six half-lives and would have approximately 2% of the ^{235}U parent isotope remaining and 98% of ^{207}Pb (see table).

Half lives	^{235}U %	^{207}Pb %	Age
0	100	0	0
1	50	50	704
2	25	75	1408
3	12.5	87.5	2112
4	6.25	93.75	2818
5	3.125	96.875	3520
6	1.5625	98.4375	4224

Not all radioactive isotopes decay over such long periods. The carbon isotope, ^{14}C , experiences a half-life every 5,730 years. ^{14}C is used to date archeological artifacts such as cloth fragments from Egyptian pyramids and organic material (e.g., bone, charcoal) found in some very young rocks (younger than 60,000 years of age).

Half-lives for Common Radioactive Isotopes

Parent Isotope	Daughter Atom	Length of Half-life	# Half-lives gone through in 1 billion years?
Rubidium 87 (^{87}Rb)	Strontium 87 (^{87}Sr)	48.8 billion years	
Uranium 238 (^{238}U)	Lead 206 (^{206}Pb)	4.5 billion years	
Potassium 40 (^{40}K)	Argon 40 (^{40}Ar)	1.25 billion years	
Uranium 235 (^{235}U)	Lead 207 (^{207}Pb)	704 million years	
Beryllium 10 (^{10}Be)	Boron 10 (^{10}B)	1.5 million years	
Carbon 14 (^{14}C)	Nitrogen 14 (^{14}N)	5,730 years	

- e. Imagine that you were analyzing a rock that was approximately 1000 million (1 billion) years old. Use labeled arrows to indicate on the graph the relative proportions of parent and daughter isotopes for each of the radioactive isotopes listed in the table above. You can fill in the column in the chart above to help get you started. (2 pts)

Analysis: Calculating the Age of North Carolina Rocks [8 pts]

11. Answer the questions that follow.

- a. If a rock started with 1,000 atoms of a parent but now contains 250 parent atoms, how many half lives have passed?
 a) 0.25 half lives c) 1 half life
 b) 0.5 half lives d) 2 half lives
- b. The half life of radioactive isotope X is 2 billion years. Approximately how much of the parent isotope and its daughter product is present in a rock that is 4.5 billion years old?
 a) 79% parent & 21% daughter c) 47% parent & 53% daughter
 b) 53% parent & 47% daughter d) 21% parent & 79% daughter
- c. Using some of the data in the tables of pages 13 and 15, complete the table below to estimate the approximate relative proportions of parent and daughter atoms in the oldest dated rock in North Carolina which has been determined to be 1.8 billion years old.

Parent	# of half-lives	% Parent isotope	Daughter	% Daughter isotope
Uranium 238 (^{238}U)			Lead 206 (^{206}Pb)	
Uranium 235 (^{235}U)			Lead 207 (^{207}Pb)	
Rubidium 87 (^{87}Rb)			Strontium 87 (^{87}Sr)	
Potassium 40 (^{40}K)			Argon 40 (^{40}Ar)	

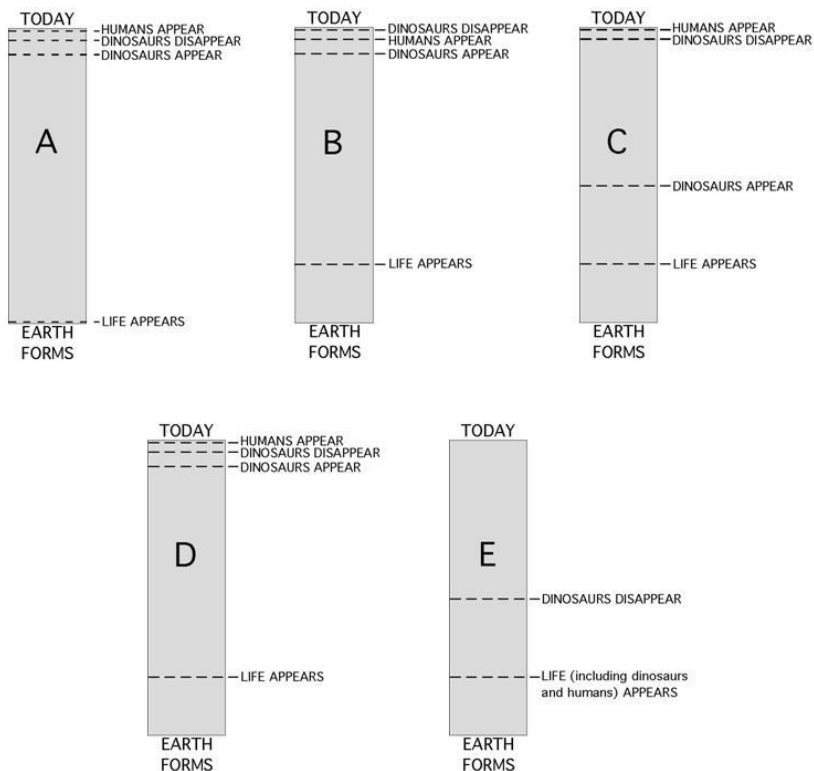
- d. C^{14} can only be used when we have organic materials which are not present in most rocks. If we were to have organic material in a 1.8 billion year old rock, how many half lives would have passed for the C^{14} isotopes?
- e. Could scientists use carbon dating techniques to determine an age for the oldest rocks in North Carolina? Explain.
- f. Could scientists use fossils to date the oldest rocks in North Carolina? Explain.
- g. Which of the radioactive elements in the table on page 7 would be the best to use to provide an accurate date on rocks that were approximately 10 million years old?
 a) ^{10}Be b) ^{87}Rb c) ^{14}C

Appendix C: Geologic Time Pre-Test

1. Scientists have discovered fossils of four-legged creatures called dinosaurs. How much time passed between the appearance and extinction of these creatures?
 - a. Hundreds of years
 - b. Thousands of years
 - c. Millions of years
 - d. Billions of years
 - e. Some of these creatures still exist

2. The element Einsteinium-253 has a half-life of 20 days. If you began an experiment with an 80-gram sample of Einsteinium-253, how much would remain after 60 days?
 - a. 60 grams
 - b. 40 grams
 - c. 20 grams
 - d. 10 grams
 - e. Not enough information provided

3. Which of the figures below do you think most closely represents changes in life on Earth over time?



4. Scientists claim that they can determine when the Earth first formed as a planet. Which technique(s) do scientists use today to determine when the Earth first formed? **Choose all that apply.**
 - a. Comparison of fossils found in rocks
 - b. Comparison of layers found in rocks
 - c. Analysis of uranium found in rocks
 - d. Analysis of carbon found in rocks
 - e. Scientists cannot calculate the age of the Earth

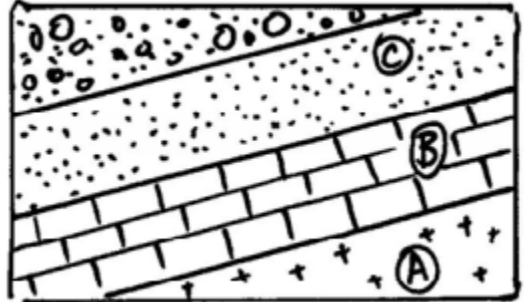
5. What do we call the feature left by a cycle involving deposition, then removal of previously deposited sediment by erosion, then a return to deposition?
 - a. An unconformity
 - b. An inclusion
 - c. A turbidite sequence
 - d. A nonconformity
 - e. A cross-cutting relationship

6. If you had a time machine and were able to travel back to the moment when the Earth formed, how far back in time would you have traveled?
 - a. 6 thousand years
 - b. 5 hundred thousand years
 - c. 6.4 million years
 - d. 4.6 billion years
 - e. 3.5 trillion years

7. An archaeologist is studying layers of human settlement in an African cave. What method of radiometric dating should they use to determine an age of woody material found at an apparent fire pit in one of the layers?
 - a. Potassium – Argon
 - b. Carbon – Nitrogen
 - c. Argon – Argon
 - d. Rubidium – Strontium
 - e. Carbon – Oxygen

8. Layer A is from the Ordovician, Layer C is from the Carboniferous. What geological time **Period** is **most likely** represented by Layer B?

- a. Lower Carboniferous
- b. Upper Ordovician
- c. Devonian
- d. Permian
- e. Paleozoic



Appendix D: Example Student Worksheet

Relative and Absolute Dating

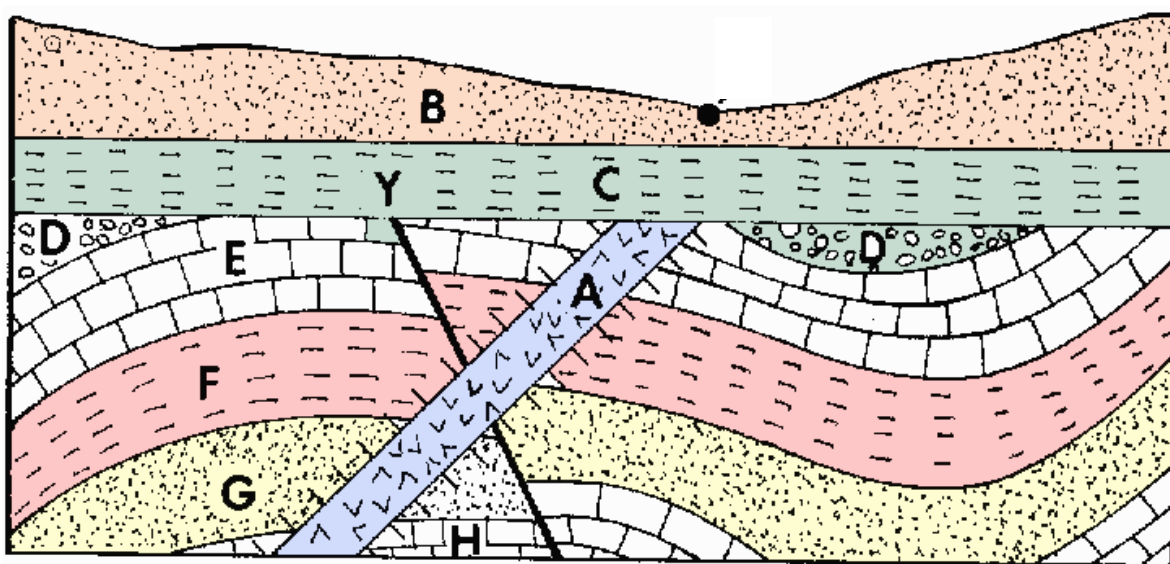
Learning Objectives:*I can...*

- Apply the stratigraphic principles to order the sequence in which rock units were formed.
- Identify if an organism would be an ideal index fossil
- Explain what happens during radioactive decay using the term element, isotope, and half-life.
- Combine the principles of relative and absolute dating to bracket the age of a fossil within a stratigraphic column.

PART 1: Principles of Relative Dating Practice

1. Arrange the events in order of oldest to youngest. Y is a fault.

Oldest _____ Youngest



2. Where is an example of an unconformity? Why type is it?

PART 2: Dinosaurs as Index Fossils

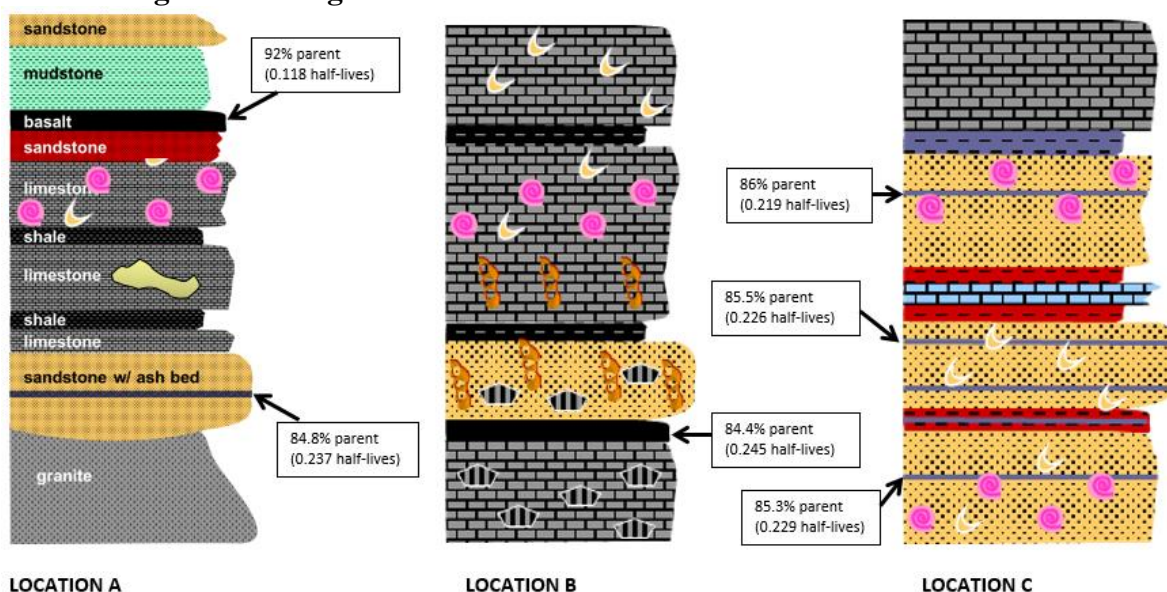
3. Take a minute to think about what makes a good index fossil and decide if dinosaurs would make ideal index fossils. Write down your answer and explain your reasoning. Discuss your answer with a neighbor and be prepared to share the results of your discussion with the class.

PART 3: Half-life Analogy Exercise

4. How many times will the class flip until there are no students left standing? _____

5. How long will this take? _____

PART 4: Age Bracketing a Fossil



6. You have found an unknown fossil bone in a limestone unit at Location A. You cannot identify it and are curious if it might be a new species of dinosaur. Use the information at Location A as well as B&C to determine the age range of your new fossil. Uranium 235 samples were taken from specific layers with the % parent and # of half-lives shown. The half-life of Uranium 235 decaying to Lead 207 is 704 million years.

What is the age range of your newly discovered fossil?

Appendix E: Reformed Teaching Observation Protocol

Reformed Teaching Observation Protocol (RTOP)

Daiyo Sawada
External Evaluator

Michael Piburn
Internal Evaluator

and

Kathleen Falconer, Jeff Turley, Russell Benford and Irene Bloom
Evaluation Facilitation Group (EFG)

Technical Report No. IN00-1

Arizona Collaborative for Excellence in the Preparation of Teachers
Arizona State University

I. BACKGROUND INFORMATION

Name of teacher _____ Announced Observation? _____
(yes, no, or explain)

Location of class _____
(district, school, room)

Years of Teaching _____ Teaching Certification _____
(K-8 or 7-12)

Subject observed _____ Grade level _____

Observer _____ Date of observation _____

Start time _____ End time _____

II. CONTEXTUAL BACKGROUND AND ACTIVITIES

In the space provided below please give a brief description of the lesson observed, the classroom setting in which the lesson took place (space, seating arrangements, etc.), and any relevant details about the students (number, gender, ethnicity) and teacher that you think are important. Use diagrams if they seem appropriate.

Record here events which may help in documenting the ratings.

Time	Description of Events

III. LESSON DESIGN AND IMPLEMENTATION

		Never Occurred					Very Descriptive				
		0	1	2	3	4	0	1	2	3	4
1)	The instructional strategies and activities respected students' prior knowledge and the preconceptions inherent therein.	0	1	2	3	4	0	1	2	3	4
2)	The lesson was designed to engage students as members of a learning community.	0	1	2	3	4	0	1	2	3	4
3)	In this lesson, student exploration preceded formal presentation.	0	1	2	3	4	0	1	2	3	4
4)	This lesson encouraged students to seek and value alternative modes of investigation or of problem solving.	0	1	2	3	4	0	1	2	3	4
5)	The focus and direction of the lesson was often determined by ideas originating with students.	0	1	2	3	4	0	1	2	3	4

IV. CONTENT

Propositional knowledge

6)	The lesson involved fundamental concepts of the subject.	0	1	2	3	4	0	1	2	3	4
7)	The lesson promoted strongly coherent conceptual understanding.	0	1	2	3	4	0	1	2	3	4
8)	The teacher had a solid grasp of the subject matter content inherent in the lesson.	0	1	2	3	4	0	1	2	3	4
9)	Elements of abstraction (i.e., symbolic representations, theory building) were encouraged when it was important to do so.	0	1	2	3	4	0	1	2	3	4
10)	Connections with other content disciplines and/or real world phenomena were explored and valued.	0	1	2	3	4	0	1	2	3	4

Procedural Knowledge

11)	Students used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena.	0	1	2	3	4	0	1	2	3	4
12)	Students made predictions, estimations and/or hypotheses and devised means for testing them.	0	1	2	3	4	0	1	2	3	4
13)	Students were actively engaged in thought-provoking activity that often involved the critical assessment of procedures.	0	1	2	3	4	0	1	2	3	4
14)	Students were reflective about their learning.	0	1	2	3	4	0	1	2	3	4
15)	Intellectual rigor, constructive criticism, and the challenging of ideas were valued.	0	1	2	3	4	0	1	2	3	4

V. CLASSROOM CULTURE

Communicative Interactions		Never Occurred					Very Descriptive				
		0	1	2	3	4	0	1	2	3	4
16)	Students were involved in the communication of their ideas to others using a variety of means and media.	0	1	2	3	4	0	1	2	3	4
17)	The teacher's questions triggered divergent modes of thinking.	0	1	2	3	4	0	1	2	3	4
18)	There was a high proportion of student talk and a significant amount of it occurred between and among students.	0	1	2	3	4	0	1	2	3	4
19)	Student questions and comments often determined the focus and direction of classroom discourse.	0	1	2	3	4	0	1	2	3	4
20)	There was a climate of respect for what others had to say.	0	1	2	3	4	0	1	2	3	4
Student/Teacher Relationships											
21)	Active participation of students was encouraged and valued.	0	1	2	3	4	0	1	2	3	4
22)	Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence.	0	1	2	3	4	0	1	2	3	4
23)	In general the teacher was patient with students.	0	1	2	3	4	0	1	2	3	4
24)	The teacher acted as a resource person, working to support and enhance student investigations.	0	1	2	3	4	0	1	2	3	4
25)	The metaphor "teacher as listener" was very characteristic of this classroom.	0	1	2	3	4	0	1	2	3	4

Additional comments you may wish to make about this lesson.

Appendix F: Beliefs about Reformed Science Teaching and Learning survey

Beliefs about Reformed Science Teaching and Learning (BARSTL)(Sampson et al., 2013)**How People Learn About Science**

The statements below describe different viewpoints concerning the ways students learn about science. Based on your beliefs about how people learn, indicate if you agree or disagree with each of the statements below using the following scale...

1: Strongly Disagree 2: Disagree 3: Agree 4: Strongly Agree

	SD	D	A	SA
1. Students develop many beliefs about how the world works before they ever study about geoscience in school.	1	2	3	4
2. Students learn in a in a disorderly fashion; they create their own knowledge by modifying their existing ideas in an effort to make sense of new and past experiences.	1	2	3	4
3. People are either talented at science or they are not, therefore student achievement in science is a reflection of their natural abilities.	1	2	3	4
4. Students are more likely to understand a scientific concept if the teacher explains the concept in a way that is clear and easy to understand.	1	2	3	4
5. Frequently, students have difficulty learning scientific concepts in school because their beliefs about how the world works are often resistant to change.	1	2	3	4
6. Learning geoscience is an orderly process; students learn by gradually accumulating more information about a topic over time.	1	2	3	4
7. Students know very little about geoscience before they learn it in school.	1	2	3	4
8. Students learn the most when they are able to test, discuss, and debate many possible answers during activities that involve social interaction.	1	2	3	4

Lesson Design and Implementation

The statements below describe different ways science lessons can be designed and taught in school. Based on your opinion of how science should be taught, indicate if you agree or disagree with each of the statements below using the following scale...

1: Strongly Disagree 2: Disagree 3: Agree 4: Strongly Agree

	SD	D	A	SA
9. During a lesson, students should explore and conduct their own experiments with hands-on materials before the teacher discusses any scientific concepts with them.	1	2	3	4
10. During a lesson, teachers should spend more time asking questions that trigger divergent ways of thinking than they do explaining the concept to students.	1	2	3	4
11. Whenever students conduct an experiment during a science lesson, the teacher should give step-by-step instructions for the students to follow in order to prevent confusion and to make sure students get the correct results.	1	2	3	4
12. Experiments should be included in lessons as a way to reinforce the scientific concepts students have already learned in class.	1	2	3	4
13. Lessons should be designed in a way that allows students to learn new concepts through inquiry instead of through a lecture, a reading or a demonstration.	1	2	3	4
14. During a lesson, students need to be given opportunities to test, debate and challenge ideas with their peers.	1	2	3	4
15. During a lesson, all of the students in the class should be encouraged to use the same approach for conducting an experiment or solving a problem.	1	2	3	4
16. Assessments in geoscience classes should only be given after instruction is completed; that way the teacher can determine if the students have learned the material covered in class.	1	2	3	4

Characteristics of Teachers and the Learning Environment

The statements below describe different characteristics of teachers and classroom learning environments. Based on your opinion of what a good geoscience teacher is like and what a classroom should be like, indicate if you agree or disagree with each of the statements below using the following scale...

1: Strongly Disagree 2: Disagree 3: Agree 4: Strongly Agree

	SD	D	A	SA
17. Students should do most of the talking in geoscience classrooms.	1	2	3	4
18. Students should work independently as much as possible so they do not learn to rely on other students to do their work for them.	1	2	3	4
19. In geoscience classrooms, students should be encouraged to challenge ideas while maintaining a climate of respect for what others have to say.	1	2	3	4
20. Teachers should allow students to help determine the direction and the focus of a lesson.	1	2	3	4
21. Students should be willing to accept the scientific ideas and theories presented to them during science class without question.	1	2	3	4
22. An excellent geoscience teacher is someone who is really good at explaining complicated concepts clearly and simply so that everyone understands.	1	2	3	4
23. The teacher should motivate students to finish their work as quickly as possible.	1	2	3	4
24. Geoscience teachers should primarily act as a resource person; working to support and enhance student investigations rather than explaining how things work.	1	2	3	4

The Nature of the Science Curriculum

The following statements describe different things that students can learn about in science while in school. Based on your opinion of what students should learn about during their science classes, indicate if you agree or disagree with each of the statements below using the following scale...

1: Strongly Disagree 2: Disagree 3: Agree 4: Strongly Agree

	SD	D	A	SA
25. A good science curriculum should focus on only a few scientific concepts a year, but in great detail.	1	2	3	4
26. The science curriculum should focus on the basic facts and skills of science that students will need to know later.	1	2	3	4
27. Students should know that scientific knowledge is discovered using the scientific method.	1	2	3	4
28. The science curriculum should encourage students to learn and value alternative modes of investigation or problem solving.	1	2	3	4
29. In order to prepare students for future classes, graduate school, or a career in science the science curriculum should cover as many different topics as possible over the course of a school year.	1	2	3	4
30. The science curriculum should help students develop the reasoning skills and habits of mind necessary to do science.	1	2	3	4
31. Students should learn that all science is based on a single scientific method—a step-by-step procedure that begins with ‘define the problem’ and ends with ‘reporting the results.’	1	2	3	4
32. A good science curriculum should focus on the history and nature of science and how science affects people and societies.	1	2	3	4

Appendix G: RTOP scores for all revised classes

		Class Number																												
		1	2	3	4	5	8	9	11	12	13	14	15	16	17	18	19	20	22	23	24	25	26	27	28	Avg				
Lesson Design & Implementation	1	2	0	1	1	1	1	1	2	1	1	1	1	2	2	1	3	1	1	1	1	2	2	2	1	1.3				
	2	2	2	1	3	3	1	2	1	2	4	1	1	2	3	3	2	3	2	1	1	1	3	2	1	2.0				
	3	2	1	1	3	3	1	2	1	2	4	2	1	2	1	2	1	1	2	2	1	1	2	2	1	1.7				
	4	3	1	1	3	2	1	2	1	1	4	1	1	3	2	1	1	1	2	1	1	1	1	1	1	1.5				
	5	2	1	1	2	2	1	1	1	2	2	1	0	1	2	1	2	1	2	1	1	1	1	2	2	1	1.4			
	T:	11	5	5	12	11	5	8	6	8	15	6	4	10	10	8	9	7	9	6	5	6	10	9	5	7.9				
Propositional Knowledge	6	2	2	3	3	3	2	3	3	4	4	4	3	4	4	4	3	4	3	3	4	3	3	3	3	3.2				
	7	2	2	2	3	3	3	3	3	3	3	4	3	4	3	4	3	4	3	3	3	3	3	3	3	3.0				
	8	4	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3.9				
	9	2	2	2	2	3	3	2	2	3	3	3	3	3	3	3	3	3	3	2	2	3	2	2	2	2.5				
	10	2	2	2	3	2	2	2	2	2	3	1	2	2	2	2	2	2	1	3	2	2	3	1	2	2.0				
T:	12	11	12	15	15	14	14	14	16	17	16	15	17	16	17	15	17	14	15	15	15	15	13	14	14.8					
Procedural Knowledge	11	2	2	2	2	2	1	2	1	3	3	1	1	2	2	3	1	2	1	1	1	1	2	2	2	1.8				
	12	3	1	1	1	2	1	2	1	1	2	1	0	2	2	2	1	1	2	2	2	1	2	1	0	1.4				
	13	1	1	1	2	3	1	1	1	1	3	0	1	1	2	1	1	1	1	1	1	1	1	1	1	1.2				
	14	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0.2				
	15	1	1	1	2	2	1	3	1	1	3	1	0	1	1	1	1	1	2	1	1	1	1	1	0	1.2				
T:	7	5	5	7	9	6	8	4	6	11	3	2	6	7	7	4	5	6	5	5	4	7	5	4	5.8					
Student-Student Interactions	16	2	2	2	3	3	0	1	1	2	4	1	1	2	2	2	0	2	3	1	1	1	3	2	1	1.8				
	17	3	2	2	3	3	1	2	1	2	3	1	2	3	2	2	1	2	3	2	2	2	2	2	1	2.0				
	18	2	2	2	3	3	0	1	1	2	4	2	2	2	3	3	0	3	2	2	1	1	2	2	1	1.9				
	19	2	1	1	3	3	0	2	1	2	3	2	1	2	3	3	0	2	2	2	1	2	2	2	0	1.8				
	20	1	1	2	2	2	1	2	1	2	3	1	1	2	3	2	1	2	2	1	1	1	1	1	1	1.5				
T:	10	8	9	14	14	2	8	5	10	17	7	7	11	13	12	2	11	12	8	6	7	10	9	4	9.0					
Student-Teacher Interactions	21	2	1	1	2	2	2	2	1	2	2	2	1	2	2	1	1	2	3	1	1	1	3	2	1	1.7				
	22	1	1	0	3	2	1	1	0	1	2	2	1	2	2	2	2	1	2	1	1	1	1	0	1.3					
	23	2	1	1	2	1	1	2	1	1	4	1	1	2	2	1	2	1	3	1	1	1	1	3	1	1.5				
	24	1	1	1	3	2	0	1	0	2	3	2	0	2	2	2	1	2	1	1	1	1	2	2	1	1.4				
	25	1	1	2	2	1	1	1	1	2	3	1	1	2	2	2	2	2	1	1	2	1	2	2	1	1.5				
T:	7	5	5	12	8	5	7	3	8	14	8	4	10	10	8	8	8	10	5	6	5	9	10	4	7.5					
TOTAL:		47	34	36	60	57	32	45	32	48	74	40	32	54	56	52	38	48	51	39	37	37	51	46	31	44.9				