

ABSTRACT

RYKER, KATHERINE DAMERON ALMQUIST. *An Evaluation of Classroom Practices, Inquiry and Teaching Beliefs in Introductory Geoscience Classrooms.* (Under the direction of David McConnell.)

The incorporation of reformed, inquiry-based pedagogies in introductory courses has been shown to improve content knowledge, student retention, interest and attitudes towards science. However, there is evidence that suggests these techniques are not being widely used by the geoscience community. This research focuses on the incorporation of inquiry-based activities in introductory Physical Geology labs and the relationship between classroom practices and teaching beliefs of geoscience instructors to better understand and address the gap between the literature and practice.

Three mixed-methods studies are described here that include classroom observations, semi-structured interviews, and assessment of classroom materials (labs). Participants include faculty members from across the country who have completed workshops through On the Cutting Edge and Graduate Teaching Assistants (GTAs) from a large, public research university in the southeast.

Providing higher inquiry labs is one way to promote reformed teaching in introductory courses. An introductory Physical Geology lab course had been designed around inquiry labs requiring student-centered pedagogy. Chapter 2 describes our efforts to assess how much inquiry is present in each lab and determine how GTAs approached teaching these activities. We use the Reformed Teaching Observation Protocol (RTOP; Sawada et al., 2002) to describe the degree of reformed instruction in a lab class using these higher inquiry Physical Geology labs. GTAs were able to teach the labs in a consistent manner, despite having

minimal instructional training. There was a moderate relationship between the RTOP score and degree to which students' grades are accounted for at higher or lower levels of inquiry.

There are a wide variety of modifiers and terms associated with inquiry that complicate efforts by instructors to identify or adopt inquiry-based activities in their own courses. In Chapter 3, we discuss several measurement protocols designed to describe to what extent inquiry is present, and select one (Buck et al., 2008) to assess the level of inquiry present in four Physical Geology laboratory manuals. One of the manuals was developed by and in use at a large, public, research university in the southeast. The majority of activities used in Physical Geology laboratory manuals are classified at low levels of inquiry that emphasize confirmation of information that is already known. This indicates that inquiry may not be one of the underlying frameworks used in their development. The university laboratory manual was developed with the goal of including more inquiry-based learning activities. It contained a significantly higher proportion of higher level inquiry activities compared to the other three lab manuals. This demonstrates that it is possible, if atypical, to incorporate higher level inquiry activities in introductory Physical Geology labs. We discuss how other instructors or lab developers can incorporate higher levels of inquiry in their labs, matching them with the type of information or skill they want students to learn.

Adoption of reformed, inquiry-based materials is at the discretion of the instructor. An evaluation of the relationship between classroom practices and teaching beliefs is therefore critical in understanding why the implementation of reformed pedagogies in the geosciences is not more widespread. Chapter 4 explores this relationship using the RTOP and Teacher Beliefs Interview (TBI; Luft and Roehrig, 2007). We identified a strong, positive correlation

between teaching practices and teaching beliefs. This indicates that both constructs are important to consider in creating professional development opportunities that encourage the implementation of reformed teaching practices. We end by discussing the role of personal practical theories and professional development in changing both practices and beliefs, and models that describe these changes.

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An Evaluation of Classroom Practices, Inquiry and Teaching Beliefs in Introductory
Geoscience Classrooms

by
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DEDICATION

This dissertation is dedicated to the memory of Dan Dalke. Words cannot describe the incredible impact Dan had on my life as a teacher, mentor, role model and friend.

BIOGRAPHY

The first “real” science field trip I can remember vividly was in 8th grade. I was in the River Kids Club, a small group of Lovett students who regularly took water quality measurements on the Chattahoochee River in Atlanta, Georgia. One week, I was the only member to show up. Mrs. Spotts, my 8th grade science teacher and homeroom advisor, said she’d still be willing to take me out in the field. I remember walking to the river and asking her about the wildflowers growing by the path – what they were called, where else they grew, etc. She told me she didn’t have all the answers, which surprised me.

At the end of 8th grade, I had to decide what classes I’d be taking in high school. I’d been in all Honors classes, and my mom recommended that I drop one to make the transition from middle school less stressful. After some discussion, I decided that the Honors class I’d drop would be Biology. I liked science, but was nervous I might not be good enough at it for high school Honors. Thank goodness.

That decision put me into Dan Dalke’s Biology class, and began my relationship with one of the most talented, knowledgeable and enthusiastic teachers the world has ever known. I learned to love science with Dan. He taught us to dissect frogs, identify dozens of trees from a single leaf or piece of bark, and construct rational scientific arguments for a nine-sided debate on the origins of life. Senior year, I took Dan’s Marine Biology class. His lessons were peppered with tales of SCUBA diving, spearfishing amongst mangrove roots, and sailing with college friends from Miami to the Bahamas. During class, we worked in small groups to develop research projects on coral propagation. The coral from our tanks ended up

populating the reef exhibit at the Georgia Aquarium. Dan taught his students the joys of maintaining a 30 gallon saltwater tank, dissecting a lemon shark, and having to get hosed down after exploring a salt marsh on a weekend field trip to UGA's Skidaway Institute of Oceanography.

After senior year, I got to go with Dan and a group of recent graduates to Siempre Verde, Lovett's research station in the upper montaine cloudforest of Ecuador. We learned about tropical ecology, took midday naps in cloth hammocks, and got beaten by a three legged dog named Tripod hiking to the top of a nearby mountain. One evening, Dan asked who wanted to go birdwatching with him. Several students volunteered, but I was the only one he could wake up before dawn the next day. This was my River Kids field trip all over again. We crouched silently in the middle of the jungle, 2,500 miles from home, trying to identify dozens of birds. I watched a hummingbird hover within arm's reach for half a minute while the morning light filtered through brilliant green leaves and dew-speckled spiderwebs. It was a magical moment. By this time, I'd learned to accept that science teachers might not have all the answers, but they knew how to help me find them. I've been on many field trips since Siempre Verde, but this remains one of my favorite field memories.

Dan's Marine Biology class was the reason I ended up majoring in Earth and Ocean Sciences at Duke, studied living coral at the Duke Marine Lab, and fossilized coral at James Cook University in Australia. Eight years after that first class with Dan, I became a high school Biology teacher myself. Later, I came to graduate school to pursue my love of science and become a better teacher. When I successfully defended my master's, I brought him the signed

title page. I was so proud to share this with him. We talked about science, teaching, travel, his children, my upcoming wedding, and the role he had played in my shaping my career. That was in December 2010, eight months before Dan ended his six year battle with multiple myeloma.

It's impossible to say how my life would be different without Dan's influence. His passion for science, teaching and family have inspired me for a lifetime.

“The day I don't learn more or change how I teach is the day I quit.” – Dan Dalke, May 2009

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I owe many people a debt of gratitude for helping me through graduate school.

Michael Ryker, thank you for being a wonderful husband and partner. Your constant love, support and encouragement have kept me going even when I struggled to see the finish line. I couldn't have done this without you.

My entire family has been a tremendous source of strength in this process. Thanks especially to Henry and Anna for love and laughs along the way. It is an honor to call you brother and sister. To my parents and grandparents, who have been lifetime supporters of higher education, thank you for supporting my dreams. My parents, Grandma, and Mike have all come to watch me teach. There's nothing quite like attending a college class in your spare time to show your love!

I would be remiss if I didn't thank the numerous students who have shared their teaching, research, and lives with me, particularly Laura Lukes, Jen Dixon, Alison Moyer, John Bedward, Sean Gallen, Nathan Lyons, Stephen Hughes, Corey Scheip, Margaret Frey, Katie Weaver, Emily Russ, Joshua Shinpaugh, Cody Hunt, and Jules Johnson. You have made graduate school such a great experience. I am thankful for the rest of the Geoscience Learning Process Research group (Michael Pelch, LeeAnna Young Chapman, Doug Czajka, April Grissom, and Hayley Smith) for their camaraderie and help making observations of the labs. Special thanks are due to Laura Lukes and April Grissom for your help co-coding interviews and lab manuals.

I want to especially acknowledge the staff, volunteers, and young ladies at the CORRAL Riding Academy in Cary. I started tutoring at CORRAL in 2009, and it was one of the best decisions I have ever made. Thanks to the staff, volunteers, girls and horses for simultaneously keeping me grounded and encouraged.

I offer my love and sincere appreciation to the Lovett teachers who made me want to follow in their footsteps, especially Dan Dalke, Mark May-Beaver, and Ken Rau. I also owe thanks to Sam Fuerst and Josh Roberts for guiding me during those early days of student teaching at Northern High School.

Finally, none of this would have happened if it weren't for Dr. David McConnell taking a chance on me as his first Ph.D. student. David has provided me with numerous opportunities to develop professionally over the past few years, and serves as a great example of someone who loves what they do. This was an adventure for both of us, and one that I wouldn't trade for anything. I owe additional thanks to David and the rest of my committee: Dr. Sandra Yuter, Dr. Meg Blanchard and Dr. Bob Beichner, for their thoughtful feedback on my work. I am excited now to take my experiences to Eastern Michigan University, and extend the reach of the Geoscience Learning Process Research group!

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Chapter 1 Introduction

Introductory geoscience classrooms offer important opportunities for college students to become scientifically literate citizens. One of the challenges of teaching these classes is the need to encourage a scientific mindset in students with diverse academic interests. Hands-on, active-learning environments have been shown to produce students who are better able to model scientific thinking, with higher order reasoning skills and a deeper understanding of the scientific process. The degree to which active-learning environments are incorporated in the classroom is up to the instructor. This is influenced by theories of instructional design (the purpose of the course and materials) and the teacher's beliefs about the teaching and learning process. Adoption of these reformed, active-learning practices can lead to improved learning gains, more positive attitudes toward science, and higher student retention rates.

This dissertation consists of three different studies. Chapters 2, 3 and 4 are presented as discrete journal articles. I use the plural 'we' to acknowledge the contributions of the coauthors on the accepted (Chapter 2) or eventual papers (Chapters 3 and 4). Chapters 2 and 3 seek to understand the extent to which inquiry-based activities are incorporated in Physical Geology laboratory manuals, and how Graduate Teaching Assistants (GTAs) teach labs that are inquiry-based. Chapter 4 is a study of the relationship between classroom practices and teaching beliefs of geoscience instructors from across the country.

Chapter 2 examines the implementation of teaching strategies by Graduate Teaching Assistants (GTAs) in inquiry-based introductory geology labs at a large research university. We assess the degree of inquiry present in each physical geology lab using the levels of

inquiry rubric developed by Buck et al. (2008), and compare and contrast the instructional practices of new and experienced GTAs teaching these labs. We demonstrate that GTAs are able to teach these labs consistently, but utilize different instructional strategies. Further, we found that the incorporation of particular teaching strategies was related to prior GTA experience. Experienced GTAs teach in a more reformed, student-centered manner than new GTAs. Teaching practices were assessed through direct classroom observation and the application of the Reformed Teaching Observation Protocol (RTOP). The lessons learned from this project can be used to inform other science departments seeking to effectively incorporate inquiry-based labs that encourage effective teaching practices from GTAs. This chapter is from the final accepted version of a peer reviewed journal article to appear in the *Journal of College Science Teaching* (Ryker and McConnell, 2014).

Many agencies, organizations and researchers have called for the incorporation of inquiry-based learning in college classrooms. However, the terminology associated with inquiry has a wide array of modifiers that complicate efforts by instructors to identify and/or adapt inquiry-based activities into their courses. In Chapter 3, we review several measurement protocols that have been developed to assess inquiry in laboratory activities. We apply one of these protocols (Buck et al. 2008) to assess the level of inquiry present in four physical geology lab manuals. Finally, we discuss how instructors can increase the inquiry level of labs or individual activities, matching them with the type of information or skill they want students to learn.

Teacher's beliefs lie "at the very heart of teaching" (Kagan, 1992, p. 85) and are a driving force behind pedagogical decisions made by all geoscience instructors. Though reformed, active-learning techniques are well established in science education research, they are not consistently translated to the classroom. Chapter 4 explores the character of teaching practices and beliefs in geoscience classrooms using the RTOP and the Teacher Beliefs Interview (TBI). We identified a strong, positive correlation between teaching practices and teaching beliefs. We also discuss the role of personal practical theories and professional development in shaping both practices and beliefs.

Chapter 2 Can Graduate Teaching Assistants Teach Inquiry-based Geology Labs Effectively?

2.1 Introduction

Introductory science labs are often more focused on the needs of individual students than a typical lecture, allowing students to gain practical knowledge of laboratory techniques, while developing conceptual and procedural knowledge and skills (Bybee, 2000; NRC, 1996). The unique strength of labs is that they can provide students with opportunities to engage in investigation and inquiry, the process of science (Hofstein and Lunetta, 1982). Further, given the longer duration and more intimate setting than conventional lectures, labs can be formatted to engage students in metacognitive activities that encourage interaction and reflection (Gunstone and Champagne, 1990).

In recent years there has been a focus on inquiry-based reform in science education (e.g., NRC, 2000). Used here, the term ‘inquiry’ follows the definition of the National Research Council (1996, p. 23), as

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

This definition focuses on the role of the student, and inquiry-based learning should therefore be understood to be student-centered. The National Science Education Standards (NRC, 2000) emphasized the nature of inquiry as existing along a continuum of learner self-direction. Inquiry-based curricula have been shown to produce higher average student achievement (Schneider, Krajcik, Marx and Soloway, 2002) and deeper student understanding of the nature of science (NRC, 2000).

Graduate Teaching Assistants (GTAs) instruct the majority of labs at research institutions (Luft et al., 2004; Sundber, Armstrong, and Wischusen, 2005; Travers, 1989) and are frequently expected to make instructional decisions, including how information should be presented, which concepts should be emphasized, and how to evaluate student work. This is often done with little direct guidance from faculty (Kurdziel and Libarkin, 2003). Unless GTAs are given the training and resources to teach effectively, introductory students may not reap the benefits of inquiry-based laboratory activities. Academic cultural norms may encourage GTAs to teach as they were taught (Halpern and Hakel, 2002). This often leads to science content, regardless of the lesson design, being delivered using methods at odds with those recommended by agencies advocating educational reforms to maximize student achievement and interest (AAAS, 1990; NRC, 1996; NRC, 2000).

We revised our introductory geology labs to include multiple inquiry activities. This article describes our efforts to assess how much inquiry is present in each lab and to determine how GTAs approached teaching these activities. The goals of this study were to:

- Measure the level of inquiry in each lab.

- Determine if GTAs will teach lab activities effectively, given a course designed around inquiry-labs requiring student-centered pedagogy.
- Describe variations in teaching practices used by new and experienced GTAs in reformed introductory geology labs.

2.1.1 Inquiry and reformed teaching

In an inquiry science lab, content is often presented through real-world problems designed to positively stimulate students' attitude toward science and their natural interest in the world around them (Hofstein and Lunetta, 2004). Positive attitudes toward, and experiences with, science may also have a direct bearing on retention rates (Moskal et al., 2004). While it would appear that labs are an ideal setting for inquiry, many college science labs are characterized by few or no inquiry activities. Buck, Bretz and Towns (2008) developed a quantitative rubric to characterize levels of inquiry in college science laboratories (Table 1). Their rubric described five levels of inquiry with the lowest level (Confirmation) providing students with the necessary problem/question, background information, procedures, method of analysis and means of communicating the results. Conclusions gained from these activities are apparent to students. For example, students may be asked to identify the elevations of several prominent features on a local area map. They are given explicit instructions on how to read the contour lines, and where on the map to find the contour interval. A fill-in-the-blank answer sheet tells students how to communicate their results. Higher level activities remove some of this guidance, encouraging students to analyze results, design procedures or even craft their own research question (Table 1). For example, in an Open activity, students

may be asked to use a physical model to test a hypothesis that earthquakes are time-predictable. They design the experiment and decide how to communicate their results. Higher level activities incorporate many of the elements of the inquiry definition above and more closely replicate the scientific method.

Buck et al. (2008) evaluated 386 laboratory experiments (activities) from a variety of undergraduate science laboratory manuals. They rated 29.8% of the activities as Confirmation, 62.2% Structured, 6.7% Guided, 1.3% Open, and 0% Authentic. Their analysis included 63 geoscience (46 geology and 17 meteorology) activities, all of which were interpreted as Confirmation, the lowest level of inquiry.

Table 1 A rubric to characterize inquiry in the undergraduate laboratory. Adapted from Table 2 from Buck, Bretz and Towns (2008).

Characteristic	Level 0: Confirmation	Level 1/2: 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

In addition to enjoyment of the tasks themselves, the positive influence of instructors in introductory science classes has been cited as a key factor associated with student persistence in science and engineering (Brainard and Carlin, 1998). Generating and sustaining student interest can be critical in improving recruitment and retention rates in geoscience programs (Moskal et al., 2004). When labs are paired with large lecture courses, GTAs often have more contact with undergraduate students than do the lecture professors (Gardner and Jones, 2011). Given the role of GTAs in teaching content and their potential impact on recruitment, it is important that we encourage the use of best teaching practices if we are to meet the growing needs of the US geoscience workforce (Geissman, 2012). Even when labs are re-designed around best teaching and learning practices, there is no guarantee that GTAs will effectively implement these practices.

A constructivist or “reformed” pedagogy (MacIsaac and Falconer, 2002) incorporates activities that encourage students to work collaboratively, analyze questions that emphasize concepts over facts, and provide opportunities for students to assess their learning and for the instructor to provide feedback (Heath et al., 2010; NRC, 2012). Reformed instruction builds on research findings about student learning and has been shown to improve conceptual knowledge and attitudes in a variety of disciplines (e.g., Crouch and Mazur, 2001; Knight and Wood, 2005; Kortz et al., 2008; Sesen and Tarhan, 2011). These practices utilize social constructivist theory (Vygotsky, 1978) that focuses on collaborative interaction amongst students and between the students and teacher. The result is an environment that helps teachers and students successfully engage in the teaching and learning process. Inquiry, as

defined above, describes the nature of lab activities while the degree of class reform reflects how the student interacts with the material, their peers, and instructor. Just as we can use a rubric to define the level of inquiry in lab activities, we can use the Reformed Teaching Observation Protocol (RTOP; Sawada et al., 2002) to describe the degree of reformed instruction in a lab class based on five subscales:

- Lesson Design and Implementation measures to what extent the design and application of the lesson draws on student input, exploration and negotiation of meaning.
- Propositional Knowledge describes whether the lesson is more fact or concept oriented, and the teacher's command of the material.
- Procedural Knowledge assesses what students were asked to do during the lesson, including making predications, forming hypotheses and engaging in self-reflection of what they know.
- Student-Student Interactions are assessed based on their quantity and quality, and the variety of scales at which they occur (e.g. pairs, small groups, whole class).
- Student-Teacher Relationships gauge how the teacher promoted active student participation, and acted as a resource person for students.

Each subscale is comprised of five statements that are ranked using a Likert scale from 0 (Never occurred) to 4 (Very descriptive of the class), for a total score of 0-100. As with MacIsaac and Falconer (2002), we will use the term reformed teaching to mean classroom

practices that result in an RTOP score of greater than 50. These are student-centered classes that feature activities that discipline-based educational research has shown to increase student learning (NRC, 2012).

2.2 Methods

This research was conducted at a large, public, research university in the southeast. The university serves more than 34,000 undergraduates and graduate students. Participating GTAs were selected based on their current involvement in teaching an introductory geology lab, willingness to participate, and the compatibility of the GTAs' and researchers' schedules for the purposes of observations. An effort was made to observe both new (first semester) and experienced (at least third semester) GTAs (Table 2).

Training for GTAs includes a university-wide half day orientation to teaching, plus a three hour departmental seminar at the beginning of the Fall semester, led by the lab supervisor. GTAs meet weekly with the lab coordinator, an experienced GTA, to review labs, discuss teaching strategies and address any classroom management issues. Experienced GTAs are encouraged to share their teaching experiences with new GTAs, and everyone can suggest improvements to the labs.

Table 2 Number of observations made of Physical Geology labs.

Semester	Total observations	Number of lab topics observed	Observations of New GTAs (1st semester)	Observations of Experienced GTAs (more than 2 semesters)
Spring 2011	20	4	0	20
Fall 2011	28	7	15	13

2.2.1 Characterizing the inquiry-based and reformed nature of the labs

We used the rubric of Buck et al. (2008) to characterize the level of inquiry in eleven Physical Geology labs. The point value for each activity was printed in the lab, visible to GTAs and students alike. Using these point values, we calculated the percentage of a student's grade earned at each level of inquiry for each lab (Figure 1). The authors established excellent inter-rater reliability ($K = 0.8496$; Cicchetti, 1994) with the rubric before characterizing all of the labs. The percentage of a student's grade attributable to an inquiry level was multiplied by the "value" of that level to calculate an inquiry score. The numeric levels provided by Buck et al. (2008) from Confirmation to Authentic are 0, $\frac{1}{2}$, 1, 2 and 3. For example, if we were to score an "average" lab analyzed by Buck et al. (2008), 30% was composed of Confirmation activities ($30 \times 0 = 0$ inquiry score), 62% was Structured ($62 \times 0.5 = 31$), 7% was Guided ($7 \times 1 = 7$), and 1% was Open ($1 \times 2 = 2$), the lab would be awarded an inquiry score of 40 points.

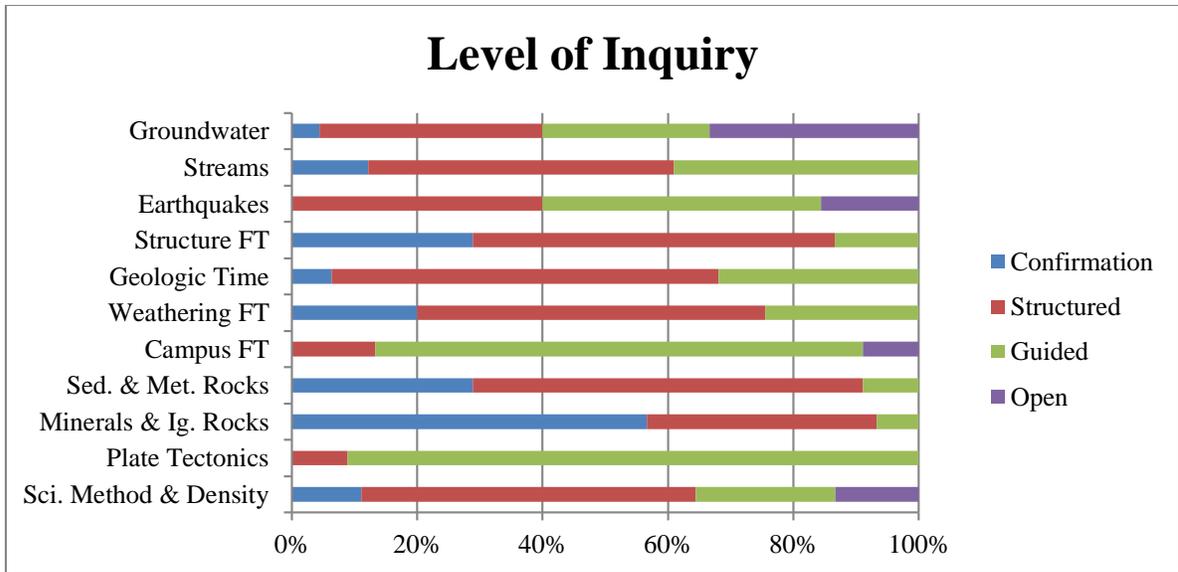


Figure 1 Percentage of physical geology students' grade attributable to each level of inquiry for eleven labs. No Authentic inquiry activities were identified in the physical geology labs. Note: FT stands for 'field trip'.

In order to measure the degree of reformed instruction in the lab, we used the detailed RTOP revised rubric and protocol as devised by Budd and others (2013). Two observers (including the first author) established excellent inter-rater reliability ($K = 0.8535$; Cicchetti, 1994). This was calculated by comparing observations made using two video lectures and two live classroom observations. GTAs were alerted prior to the observation of each lab and observers spent a minimum of one hour in the classroom before scoring.

2.3 Results

2.3.1 Levels of inquiry in introductory geology labs

The Physical Geology labs were characterized by a range of levels of inquiry (Figure 1). On the basis of the classification system of Buck et al. (2008), the Physical Geology labs were found to contain 15.3% Confirmation, 43.1% Structured, 35.1% Guided, 6.5% Open, and 0% Authentic activities. All of the labs contained some Confirmation or Structured activities, which were often used to familiarize students with new material. However, the Physical Geology labs featured a higher proportion of Guided and Open activities than what had been identified in lab manuals by Buck et al. (2008), where a majority of activities featured low levels of inquiry. Physical Geology labs averaged an inquiry score of 70.5, ranging from 25.0 (Minerals and Igneous Rocks) to 111.11 (Groundwater; Figure 2). There is a significant correlation between the inquiry score and average RTOP score earned by each GTA teaching the observed labs ($r(7) = 0.61$, $p = 0.07$; Figure 3).

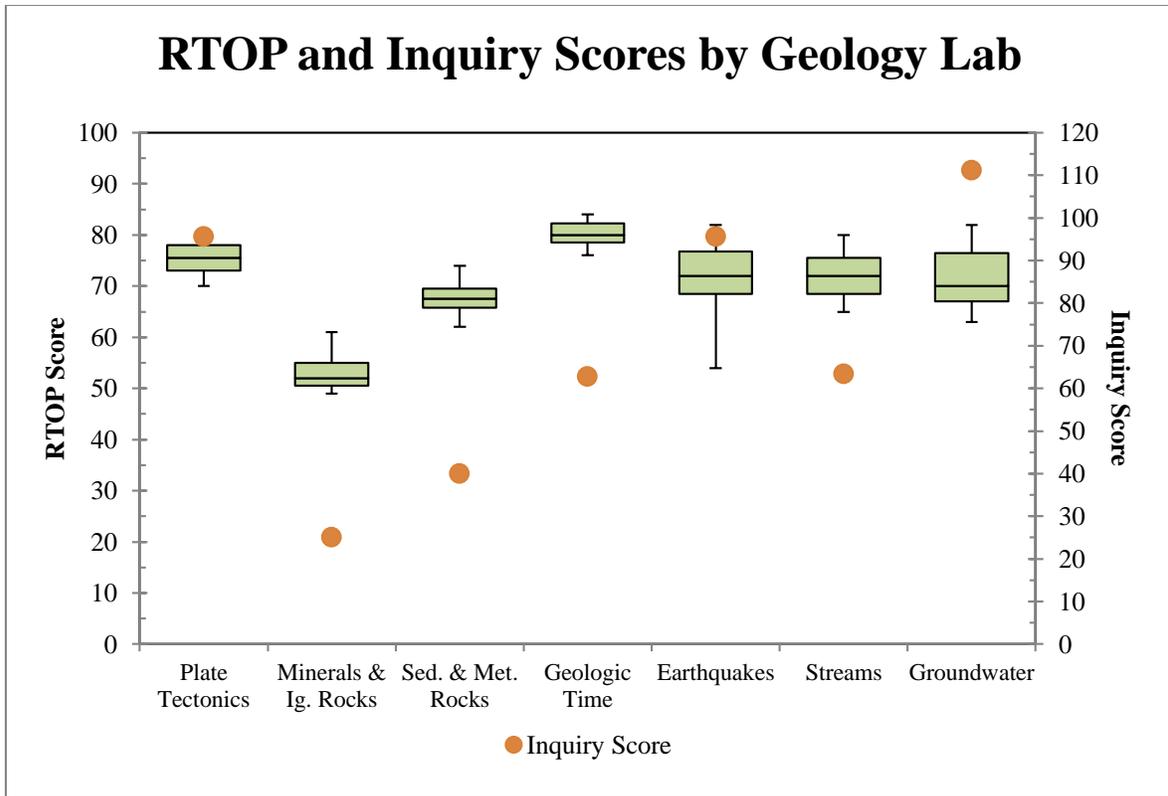


Figure 2 Comparison of the average RTOP score for seven of the physical geology topics with the degree to which the lab is inquiry-based.

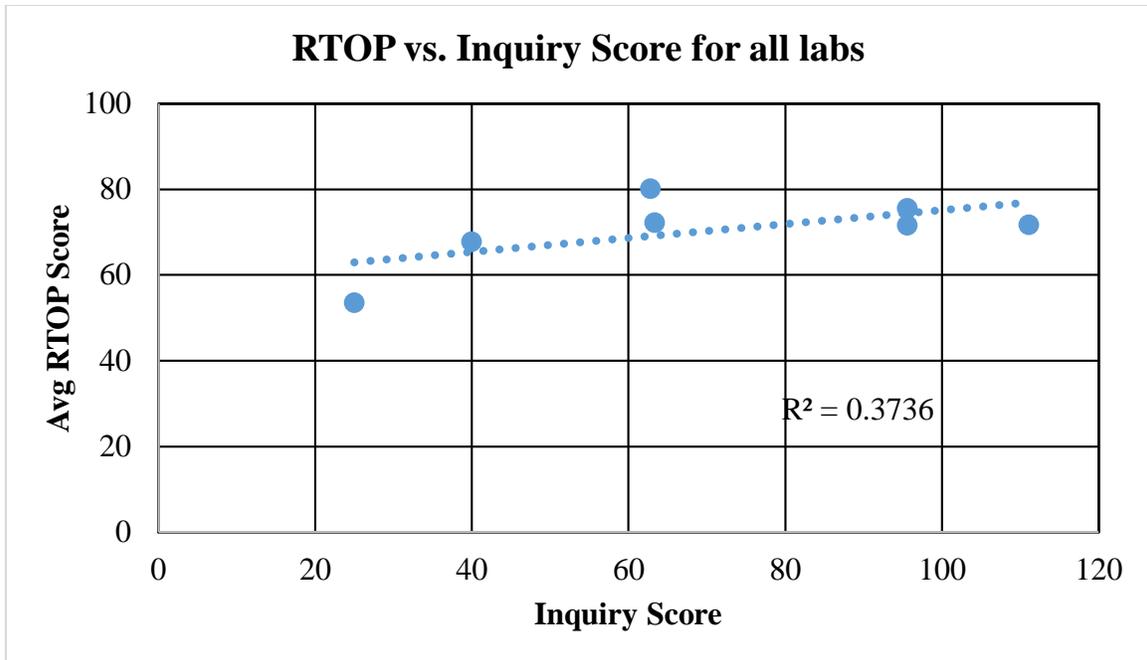


Figure 3 Relationship between Inquiry and average RTOP scores.

2.3.2 Will GTAs teach in a consistently reformed fashion, given a course designed around reformed, student-centered principles?

Eleven Physical Geology labs are taught each semester. We did not observe the first lab or the three involving field trips. At least four classes taught by different GTAs were observed for each of the remaining seven labs. RTOP scores ranged from a low of 49 for a GTA teaching the Minerals and Igneous Rock lab to a high of 84 for a GTA teaching the Geologic Time lab. With one exception, all labs were credited with high RTOP scores (MacIsaac and Falconer, 2002; Figure 2). This was true regardless of whether the GTAs were new or experienced.

2.3.3 How do teaching practices vary for new and experienced GTAs in these introductory geology labs?

Experienced GTAs out-score novice instructors on all five RTOP subscales, but there was a statistically significant difference on three of them (Table 3; Figure 4). Experienced GTAs taught in a more reformed manner on subscales measuring Propositional Knowledge, Procedural Knowledge, and Student-Teacher Relationships. There was no significant difference on Lesson Design and Implementation or Student-Student Interactions.

Table 3 Average score earned by Physical Geology GTAs on each RTOP item and subscale.

RTOP Subscale item	Experienced physical geology GTAs	New physical geology GTAs
1	2.3	2.0
2	3.5	3.3
3	3.2	3.4
4	3.1	2.9
5	2.8	2.5
Total: Lesson Design & Implementation	14.9	14.1
6	3.2	2.9
7	3.2	2.9
8	3.9	3.8
9	2.8	2.7
10	2.8	2.4
Total: Propositional Knowledge	16.1	14.6
11	3.5	3.5
12	3.1	3.1
13	3.0	2.3
14	1.8	1.1
15	2.3	2.1
Total: Procedural Knowledge	13.8	12.3
16	2.3	1.9
17	2.6	1.9
18	3.8	3.5
19	2.8	2.3
20	3.2	3.1
Total: Student-Student Interaction	14.7	12.9
21	2.9	2.3
22	2.8	2.1
23	3.1	1.9
24	3.0	2.6
25	3.2	2.7
Total: Student-Teacher Interaction	15.0	11.7
RTOP Total	74.4	65.5

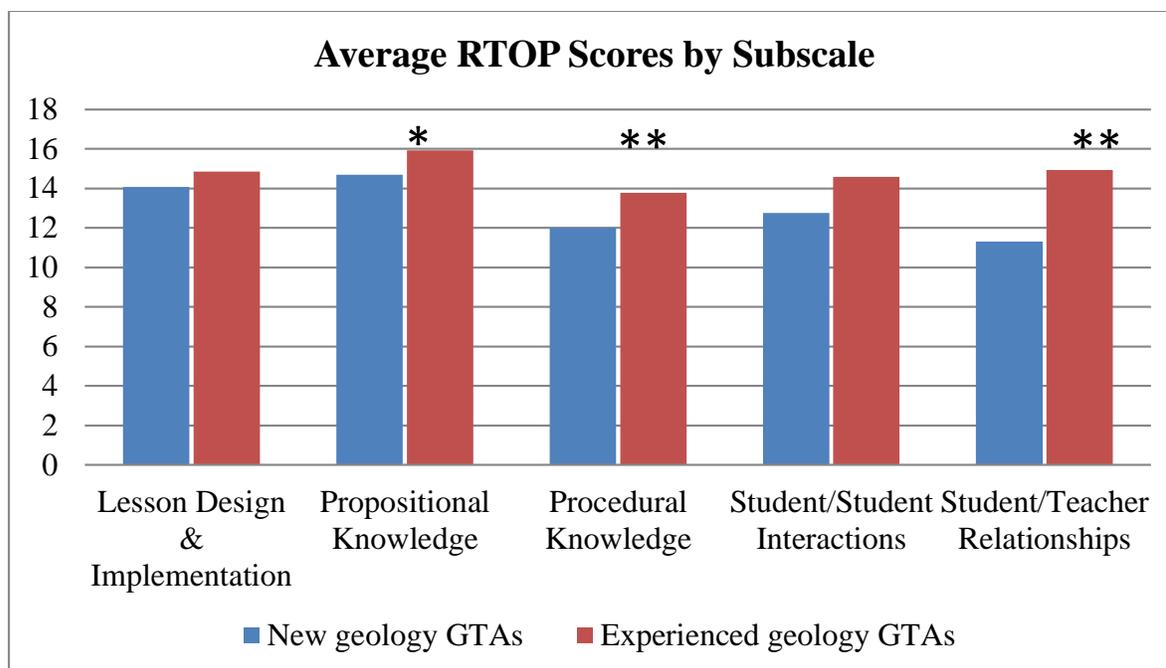


Figure 4 A comparison of average RTOP scores earned in each of the five subscales by new and experienced geology GTAs. Statistical significance calculated using Kruskal-Wallis analysis: Single asterisk (*) denotes $p < 0.05$; double asterisks (**) denotes $p < 0.01$.

2.4 Discussion

We identified a higher proportion of Guided and Open inquiry activities in the Physical Geology labs than that identified by Buck et al. (2008) in undergraduate science lab manuals. This means a shift away from the lower levels of inquiry (Confirmation, Structured). These lower levels of inquiry emphasize the nature of science as a collection of facts, rather than a process, so this change may lead to a deeper student understanding of the nature of science. Despite the overall increase in inquiry, two of the Physical Geology labs (Minerals and Igneous Rocks, Sedimentary and Metamorphic Rocks) contained more than 90%

Confirmation and Structured inquiry activities (Figure 1). These labs will be targeted for future changes to bring the degree of inquiry in line with the remainder of the labs. Further work is needed to determine whether students learn more in higher inquiry Physical Geology labs.

When provided with an inquiry lab format, GTAs exhibit a range of reformed teaching practices (as evidenced from scores ranging from 49-84 across multiple labs). There is a moderate relationship between the average RTOP score and the degree to which students' grades are accounted for at higher or lower levels of inquiry (Figure 3). Therefore, most of this variation is interpreted to be a consequence of the nature of the lab activities, rather than the GTA. This correlation between reformed teaching and inquiry suggests that, while the two are linked, the degree of reform is also dependent on other features, potentially including instructor, class size, and student engagement. Providing higher inquiry labs is one way to promote reformed teaching in introductory courses.

Physical Geology GTAs were able to teach in a reformed fashion, despite having relatively minimal instructional training. That new and experienced GTAs had similar scores on the Lesson Design subscale suggests that the labs are set up to ensure some consistency in the application of reformed pedagogy. We anticipated little variation in Lesson Design as the labs were designed by the lab supervisor, rather than the GTAs themselves, and GTAs are instructed how to teach the labs during weekly meetings. Experienced GTAs displayed significantly higher Propositional Knowledge and earned higher scores in the Procedural Knowledge and Student-Teacher Relationships subscales. Propositional Knowledge

describes what the teacher knows and how well they are able to organize and present the material conceptually, rather than as a series of facts. The significant difference in this subscale is not a reflection of the knowledge of the GTAs. Instead, it stems from the number and quality of connections made between labs and the real world, or the current lab with prior labs (item 10 in Table 3). Experienced GTAs did a better job of either making those connections themselves, or asking students to provide them. Higher scores were often earned through detailed discussions between students and teachers.

The Procedural Knowledge subscale is linked through a construct of inquiry with a number of items from the Lesson Design and Implementation subscale (Piburn and Sawada, 2000). Experienced GTAs were more likely to ask divergent questions (more than one “right” response), and allow questions and comments from students to determine the focus and direction of classroom discourse. They were also more likely to ask students to develop alternative solutions, question their assumptions, and consider why they were using a procedure. This resulted in higher scores on the Student-Teacher Relationships subscale for experienced GTAs. Higher scores in this subscale were primarily a result of the teacher engaging students in meaningful conversations that could change the direction of the lesson. Some of these differences may be a result of increased experience with the way the labs run. When asked about their teaching, new GTAs revealed that they are less comfortable diverging from the lab as written, and so stifle some of the natural discussion if they feel it is off track. For new GTAs, questions and comments rarely changed the focus and direction of classroom discourse, but instead were addressed individually. New GTAs tended to end

discussions as soon as a single correct answer was reached; experienced GTAs were more likely to push for alternative answers. Experienced GTAs were more patient and encouraging with students as they experienced the challenges of the scientific method. They allowed students to spend time identifying and discussing additional problem-solving strategies. Comments from experienced GTAs revealed that the familiarity with the lab reduced their cognitive load, allowing them to incorporate additional references that went beyond basic instruction as defined by the lab activities. It may also create an increased level of comfort in predicting and addressing common student challenges.

We interpreted the lack of contrast in the Student-Student Interactions scores of novice and experienced GTAs to mean that they are more dependent on how the lab is structured than the GTA's familiarity with the lab materials. For example, an activity that instructs groups to draw geologic cross-sections, trade them between groups and discuss differences in interpretations does not require much input from the GTA. Instructions included in the lab can provide guidance that ensures more interactions between students.

We have shown that we can readily apply tools to measure the level of inquiry and the degree of reformed teaching exhibited by GTAs in geology labs. If the labs are designed with the goal of supporting both the GTAs and undergraduate students, the GTAs need relatively minimal instruction to teach in a reformed manner, and will improve their instruction with time. A weekly lab meeting with the lab coordinator where GTAs discussed how to teach the labs and address any classroom management issues was sufficient instruction to ensure a high degree of consistency in teaching techniques for inquiry-based geology labs. It is worth

repeating that at these meetings, GTAs were encouraged to share their teaching experiences or suggestions for improvements to the lab. This appeared to help foster a culture that encouraged GTAs to reflect on and value their teaching responsibilities, rather than defer to academic cultural norms that value more traditional teaching techniques (AAAS, 1990; Halpern and Hakel, 2002; NRC, 1996; NRC, 2000). Some guidance can be provided in the lab itself to ensure labs are taught consistently. These results hold promise for science departments hoping to effectively incorporate inquiry-based labs in their curriculum, while encouraging effective teaching practices among their GTAs.

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Chapter 3 Assessing Inquiry in Physical Geology Laboratory Manuals

3.1 Introduction

Calls for science education reform have been widespread in the U.S. for decades (e.g., AAAS, 1990; DeBoer, 1991; Novak, 1988; NRC 1996; Schwab, 1962) and have targeted university and college science professors, who play a critical role in how society will learn its science (Siebert and McIntosh, 2001, p. ix). Reform that incorporates inquiry in the classroom is recognized as one way in which we can improve conceptual knowledge and attitudes in a variety of STEM fields (e.g., Beichner et al., 2007; McConnell et al., 2006; Prince, 2004; Wood, 2009). Inquiry-learning parallels the process of scientific inquiry, and focuses on the students' role in asking and investigating scientific questions and constructing a strong conceptual understanding of science (NRC, 2000). Inquiry-based classrooms are characterized by student-centered, rather than teacher-centered instruction (Buck et al., 2008). While there is broad support for the incorporation of inquiry-based learning in geoscience labs and other science courses, the terminology surrounding inquiry is often inconsistent. There is also relatively little guidance available for instructors about what constitutes an inquiry-based exercise and how they might adapt existing activities to increase the level of inquiry. The goal of this study was to assess the level of inquiry used in topics commonly covered in Physical Geology laboratory courses.

The design of instructional materials, including laboratory manuals, should take into account appropriate pedagogical techniques in order to enhance the teaching and learning process.

Instructional design is "the systematic and reflective process of translating principles of

learning and instruction into plans for instructional materials, activities, information resources, and evaluation" (Smith and Ragan, 2005, p. 4). Though instructional design has many definitions, they all reflect underlying philosophies of the learning process (Siemens, 2002).

We apply an inquiry classification scheme to a series of activities across six topical physical geology labs taken from four different sources (three published lab manuals and one self-produced departmental resource). We also make recommendations for how to increase the level of inquiry activities included in these labs, scaffold the incorporation of higher inquiry activities so that students have the greatest opportunity for success, and identify when it is appropriate to use different levels of inquiry.

3.1.1 Benefits of inquiry-based labs

Inquiry-based classrooms are beneficial for a number of reasons. Inquiry plays an important role in attracting, engaging and retaining students (Bopegedera, 2011; Moskal et al., 2004). Students may initially resist inquiry-based instruction in labs due to the increased effort required and reluctance to take control of their learning (Deters, 2005). However, they also experience a sense of accomplishment from mastering material, improve their communication skills, and can better identify and explain erroneous results (Deters, 2005). Students in classrooms utilizing these activities show higher average achievement (Deters, 2005; Kanter and Konstantopoulos, 2010; Schneider et al., 2002) and deeper understanding of the nature of science than their peers in traditional classrooms (NRC, 2000). Middle and high school students showed higher knowledge gains and retention when in higher inquiry

labs than in traditional, verification style labs (Blanchard et al., 2010). This was especially true for the older high school students, and if the teachers themselves used more reformed teaching techniques (Blanchard et al., 2010). At the college level, students in physical geology labs had greater increases in their conceptual model development of sand-sediment transport when taught in an inquiry-based learning module versus a traditionally structured, workbook style laboratory exercise (Miller et al., 2010).

Not all laboratory activities need to be inquiry-based for maximum learning gains.

Timmerman et al. (2008) used a mix of inquiry-based and traditional laboratory activities in an introductory college biology class. They found significant student gains in pre-post tests on abstract topics (such as evolution) when inquiry-based activities were used. However, more descriptive, concrete topics (such as anatomy) could be taught effectively using traditional didactic methods (Timmerman et al., 2008). Others have found similar results by analyzing concepts taught in an introductory biology course. Students more effectively mastered abstract, theoretical concepts than descriptive topics when taught using inquiry-based pedagogies (Lawson et al., 2000a; Lawson et al., 2000b). Several researchers advise careful scaffolding of learning to help students achieve success with higher levels of inquiry (Eick et al., 2005; Volkman and Abell, 2003). Because of the benefits of inquiry-based labs, we expect inquiry to be incorporated into the design of the laboratory manuals, especially in more abstract concepts.

3.1.2 Challenges of incorporating inquiry

There are several challenges to incorporating inquiry-based teaching strategies in introductory geoscience classrooms. These include the availability of resources (e.g. educational materials, instructional preparation time), situational factors (e.g. time constraints, large class sizes, disjointed lecture and laboratory classes), teacher awareness of instructional practices, and teaching beliefs and values that support change (Anderson, 2002; Barab and Luehmann, 2003; Edelson et al., 1999; Gess-Newsome et al., 2003; Sundberg et al., 2000; Zion and Mendelovici, 2012). Trumbull et al. (2005) described the necessity of the instructor integrating the learning of content knowledge with learning about inquiry in order to maximize the impact of inquiry-based materials. This means that an instructor must be familiar with both their content and inquiry-based teaching.

This raises another important challenge: the lack of consistent definitions for what constitutes inquiry. Inquiry has been used to refer to the way we teach, a method for conducting research (how we “do science”), or the way students learn (Colburn, 2000; Flick, 1995; NRC, 2000). Additionally, the term ‘inquiry’ has been given numerous modifiers, such as traditional, guided and structured, that lack a common meaning in the literature (Buck et al., 2008). This makes a direct comparison of study results more difficult. The ability to classify the level of inquiry present in an activity is an important first step in determining whether the degree of inquiry students engage in results in increased content mastery, interest and skill development.

3.1.3 Assessing inquiry

The National Science Education Standards describe five essential features of inquiry that involve the learner: 1) engaging in scientifically oriented questions; 2) giving priority to evidence in responding to questions; 3) formulating explanations from evidence; 4) connecting explanations to scientific knowledge; and, 5) communicating and justifying explanations (NRC, 2000, p. 29). In this context, inquiry is characterized as continuum of learner self-direction (NRC, 2000). The degree of self-direction is largely dictated by the teacher or instructional materials, such as a laboratory manual.

Multiple scales for classifying the type of inquiry present in a lesson have been developed. Early methods for characterizing inquiry assessed lab exercises on whether they provided students with the question to be answered, the data collection methods to answer the question, and the interpretation of results (Herron, 1971; Schwab, 1962). The level of inquiry is determined by which of these features are given to students and which are open for exploration (Table 1). Students had lower levels of independence on low level inquiry activities where all elements of an activity were provided (Table 1). In contrast, high levels of inquiry characterized exercises where the student acted independently to create their own question, collect the necessary data, and interpret their results (Schwab, 1962; Table 1).

Table 1 Schwab’s levels of inquiry (Schwab, 1962)

Inquiry Level	Level 0	Level 1	Level 2	Level 3
Source of the Question	Given by teacher	Given by teacher	Given by teacher	Open to learner
Data Collection Methods	Given by teacher	Given by teacher	Open to learner	Open to learner
Interpretation of Results	Given by teacher	Open to learner	Open to learner	Open to learner

Wenning (2005) expanded on these and other early rubrics (including Colburn, 2000; Herron, 1971; Staver and Bay, 1987) by incorporating the concept of intellectual sophistication.

Higher levels of intellectual sophistication require a shift from concrete to abstract reasoning.

Wenning (2005) developed a hierarchy of nine different levels of inquiry, including three specifically dedicated to types of inquiry labs: guided, bounded and free (Table 2). Much like the features described by the NRC (2000) continuum, these levels are positioned along a continuum of intellectual sophistication (from low to high) and locus of control (from teacher to student).

Table 2 Hierarchy of inquiry-oriented science teaching practices (Wenning, 2005)

Discovery Learning	Interactive Demonstration	Inquiry Lesson	Guided Inquiry Lab	Bounded Inquiry Lab	Free Inquiry Lab	Real-world Applications	Pure Hypothetical Inquiry
							Applied Hypothetical Inquiry
Low		Intellectual Sophistication				High	
Teacher			Locus of Control			Student	

The distinction between guided, bounded and free inquiry labs was again based on the amount of independence given to students in identifying the question to be asked and the procedures to be used. The descriptions of these are similar to how Schwab (1962) defined his levels 1, 2 and 3. Brown et al. (2006) developed a similar inquiry continuum that categorized activities from more to less student guidance (Figure 1). A unique aspect of this inquiry assessment protocol is that it allows activities to be described as a high level of inquiry while still being teacher-directed. For example, an activity in which the teacher provides the question and activities (procedures and results analysis) would be labeled full, guided inquiry (point A in Figure 1). An activity is labeled full, partial or no inquiry on the basis of which of the essential features of inquiry described by the NRC (2000) are included. While the inquiry classification schemes of Schwab (1962), Wenning (2005) and Brown et al. (2006) provide a framework for analysis, they often lack concrete definitions of discrete levels of inquiry and thus are challenging to apply to characterize lab activities. Further, the uses of the continua make the labels difficult to apply consistently. This leads to activities

that could be labeled as “guided” in one study, and “structured” in another (Buck et al., 2008).

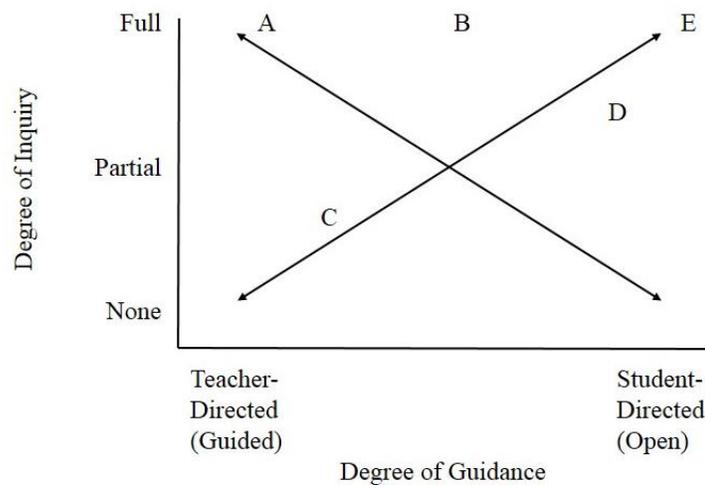


Figure 1 The inquiry continuum (Brown et al., 2006).

The quantitative rubric developed by Buck et al. (2008) provides concrete definitions for five levels of inquiry in laboratory activities. These are: Confirmation (Level 0), Structured (Level ½), Grounded (Level 1), Open (Level 2) and Authentic (Level 3) (Table 3). The inquiry level is determined on the basis of the following six elements of each activity: a) problem/question, b) theory/background, c) procedures/design, d) results analysis, e) results communication, and f) conclusions. The more of these elements that are provided for the student, the lower the inquiry level (Table 3). For example, the lowest inquiry level (Level 0) is Confirmation (Buck et al., 2008). An inquiry activity that provides students with a task and

walks them through the steps necessary to complete the task effectively (Table 3) is typically a Confirmation level activity. A student following instructions to identify a mineral or read an elevation from a topographic map would be completing a confirmation task. A Structured inquiry activity would ask students to come up with their own method of communicating their results, but would provide the question, background information, procedures and method of analyzing results. For example, a Geologic Time lab could provide students with background information on radioactive decay and a graph plotting parent and daughter isotopes over time. Students are provided with the half-life of several radioactive elements and have to identify which would be the best to use to provide an accurate date on rocks of different ages. An example of a Guided inquiry activity would be to have students decide how they could estimate the size of a drainage basin when provided with a topographic map. A kilometer grid has already been overlaid on the map, giving students a hint as to what procedures to use. However, they are not given explicit instructions on how to analyze the results of their observations. An inquiry activity that only provides students with the question and background would be classified as Open. For example, students are presented three hypotheses that describe earthquakes as periodic, time-predictable or random. Students must design and conduct an experiment to determine which of these hypotheses best describes the movements that occur using the earthquake machine model. They come up with the experimental procedures, and decide how analyze and communicate their results. Authentic inquiry activities would require students to generate their own research question and design a method for testing and analyzing the results.

Table 3 Rubric to characterize inquiry in the undergraduate laboratory (Modified from Buck et al. 2008).

Characteristic	Corresponding essential feature of inquiry (NRC, 2000)	Level 0: Confirmation	Level ½: Structured inquiry	Level 1: Guided inquiry	Level 2: Open inquiry	Level 3: Authentic inquiry
Problem/Question	Engaging in scientifically oriented questions	Given by teacher	Given by teacher	Given by teacher	Given by teacher	Open to learner
Theory/Background	Giving priority to evidence in responding to questions	Given by teacher	Given by teacher	Given by teacher	Given by teacher	Open to learner
Procedures/Design		Given by teacher	Given by teacher	Given by teacher	Open to learner	Open to learner
Results Analysis	Formulating explanations from evidence	Given by teacher	Given by teacher	Open to learner	Open to learner	Open to learner
Results Communication	Communicating and justifying explanations	Given by teacher	Open to learner	Open to learner	Open to learner	Open to learner
Conclusions	Connecting explanations to scientific knowledge	Given by teacher	Open to learner	Open to learner	Open to learner	Open to learner

The Buck et al. (2008) rubric provides a range of levels that allow an instructor to readily distinguish between varying degrees of student independence in laboratory exercises. The discrete labels tied to that independence, plus the descriptions in the original article, bring clarity to a wide number of inquiry modifiers and provides an opportunity for this protocol to be consistently applied. These characteristics Buck et al. (2008) used to define the levels of inquiry reflect the NRC's definition of inquiry and the scientific method (Table 3; NRC, 2000).

Buck et al. (2008) applied their rubric to evaluate 386 laboratory experiments in undergraduate science laboratory manuals. Each laboratory topic was counted as a separate experiment. The majority of these were rated as Confirmation (29.8%) or Structured (62.2%). Buck et al. included 46 labs from geology laboratory manuals, all of which they rated as Confirmation, the lowest level of inquiry. Ryker and McConnell (in press) applied this rubric to individual activities in Physical Geology labs in an analysis of inquiry and teaching practices at a single institution. In that study, the majority of activities were rated at Structured (43.1%) or Guided (35.1%) inquiry levels. Here we extend that analysis to characterize lab activities from multiple lab manuals and discuss how instructors can incorporate inquiry-based exercises into labs.

3.2 Methods

We analyzed labs from four physical geology lab manuals. One of the manuals (NCSU Physical Geology lab manual, 2013) selected for analysis was developed specifically for the physical geology lab course at the authors' institution. These materials were created and collected by the authors with assistance from several graduate students. Several activities are publically available from the Science Education Resource Center (SERC) or were shared by colleagues. (The most recent versions of each lab are available here:

https://sites.google.com/site/geosciencelearning/research/ncsu_meal10_labs.) The labs related to minerals, rocks, and geologic time have undergone revision to incorporate higher levels of inquiry since the analysis presented in this paper. Other researchers have reported those changes, and related improvements in student performance, perceptions of relevance

and situational interest (Czajka, 2014; Grissom, 2014). The other three manuals are published and used in Physical Geology lab courses across the country. These are referred to herein as the AGI/NAGT (Busch, 2011), Zumberge (Rutford and Carter, 2014), and Ludman and Marshak (Ludman and Marshak, 2012) lab manuals. The manuals sampled were selected to represent the most recent edition of successful publications from multiple publishing companies. The AGI/NAGT and Zumberge manuals are in their 9th and 16th editions respectively. We assume that these are reasonably typical of other published geology manuals. We selected six topics that were covered in all four lab manuals: Minerals, Groundwater, Streams, Earthquakes, Geologic Time and Plate Tectonics. Each lab was broken up into activities, based on whether questions were presented as a related group. For example, some activities were separated by headings, but contained multiple related questions. A total of 516 questions in 159 activities were examined.

We used the rubric from Buck et al. (2008) to characterize the level of inquiry for each activity within each of the six topics discussed in all four lab manuals. Examples of activities used in Physical Geology labs that are representative of the different levels of inquiry are described in post hoc paired comparison test was used to determine which groups differed from one another (Table 4).

For each activity, an inquiry score was calculated using the scale and numeric levels provided by Buck et al. (2008). The five levels and numeric levels are: Confirmation (0), Structured ($\frac{1}{2}$), Guided (1), Open (2) and Authentic (3). Each lab activity was assigned an inquiry level and we determined the proportion of each lab composed of activities at each

level. We multiplied those values together and added the resulting scores for each level to determine a total inquiry score. For example, if we were to evaluate a lab with eight exercises, six of which were Structured and two of which were Guided, we would calculate the score for the lab as 75% Structured (75×0.5) and 25% Guided (25×1), for a total inquiry score of 62.5. This differed from the original Buck et al. (2008) method of assigning a single level to an entire lab topic. Our approach allowed for a more fine-grained examination of the labs.

Two researchers independently coded 43 lab activities, 21 of which were from the NC State lab manual. This was done to ensure the rubric was used consistently, as well as to minimize potential confirmation bias. The researchers began with a subset of 12 activities and explained their reasoning for each activity on which their coding did not match. They then evaluated all 43 activities based on the negotiated meaning. Through this process, the co-coders established good inter-rater reliability ($K = 0.898$; Cicchetti and Sparrow, 1990), before the first author characterized the rest of the lab exercises.

The non-parametric Kruskal-Wallis test was used to determine whether there were statistically significant differences between inquiry scores for activities in the four lab manuals and for activities associated with the six lab topics (Kruskal and Wallis, 1952). A non-parametric statistic test was selected because the inquiry scores were not normally distributed amongst labs or lab topics. If a significant difference was identified at $p < 0.05$, a post hoc paired comparison test was used to determine which groups differed from one another.

Table 4 Sample activities for each lab topic at differing levels of inquiry.

	Level of Inquiry			
	Confirmation	Structured	Guided	Open
Characteristics provided for students:	Problem/question; theory/background; procedures/design; results analysis; results communication; conclusions	Problem/question; theory/background; procedures/design; results analysis	Problem/question; theory/background; procedures/design	Problem/question; theory/background
Minerals	Student sketch samples of quartz and halite before and after breaking them with a hammer. They use these to say whether the minerals display cleavage or fracture. (NC State, p. 8)	After categorizing an unknown set of minerals and rocks into groups based on their own criteria (see Guided example), students are asked to compare their results with those of others in the class, and say what this comparison tells them about the process of classification. (Ludman and Marshak, p. 51)	Students are given an unknown set of minerals and rocks. They group them into categories they believe are justified by their observations, making their grouping criteria explicit. (Ludman and Marshak, p. 50)	None identified.

Table 4 (continued)

	Level of Inquiry			
	Confirmation	Structured	Guided	Open
Plate Tectonics	<p>Students are provided with a map showing the relief of Earth’s surface features, and asked to copy over the boundaries of the tectonic plates from another map. Students then answer questions like: which plates do not contain significant areas of continental landmasses, or name the plates bounded by the East Pacific Rise. (Zumberge, p. 257)</p>	<p>Students are provided with a list of the largest and deadliest earthquakes of the past seven years. They are asked to provide at least two possible explanations for why the largest magnitude earthquake was not the deadliest earthquake for five of the seven years. (NC State, prelab)</p>	<p>Discovering Plate Boundaries activities, as described by Sawyer (http://plateboundary.rice.edu/). In these activities, students are asked to make observations based on four global data maps. They then work together in a jigsaw activity to describe multiple plate boundaries on the basis of their observations (problem/question). Students are not given explicit instructions on how to analyze the results of their observations. (NC State, p. 2-7)</p>	<p>None identified.</p>

Table 4 (continued)

	Level of Inquiry			
	Confirmation	Structured	Guided	Open
Geologic Time	<p>Students are given a picture that they are told is of inclined beds with a cross cutting feature and asked to determine which is younger. In the preceding text, students are told that “if one rock cuts across another, it must be younger than the rock that it cuts”. (Ludman and Marshak, p. 419-420)</p>	<p>Students apply the principles of relative dating to a cross section diagram to place the rocks in the correct sequence from youngest to oldest. (NC State, p. 5)</p>	<p>Students are asked why zircon sand grains found on a modern beach would not yield modern age using absolute age dating. Using their answer, they define a rule geologists should follow when they date rocks according to radiometric ages of crystals inside the rocks. (AGI/NAGT, p. 190)</p>	<p>None identified.</p>
Earthquakes	<p>Students use a travel-time curve graph to determine the distance from an earthquake’s epicenter at three different seismic stations. (Zumberge, p. 246)</p>	<p>Students are given the time interval between the arrival of P and S waves and asked to explain how the interval changes with distance from the epicenter. (AGI/NAGT, p. 357)</p>	<p>Students make a prediction about why different seismic waves make the ground shake differently at an earthquake epicenter versus far from it. (Ludman and Marshak, p. 396)</p>	<p>Using an earthquake simulation machine, students must design and conduct an experiment to determine whether the movements that occur with the model are best described as periodic, time-predictable, or random. (NC State, p. 7)</p>

Table 4 (continued)

	Level of Inquiry			
	Confirmation	Structured	Guided	Open
Streams	Students determine the elevation of multiple points on an idealized hypothetical topographic map. They also determine the direction of stream flow, with a reminder that water flows down hill. (AGI/NAGT, p. 261)	Students are asked to calculate the stream discharge using a stopwatch, tennis ball and meter stick. They are told to make measurements in several places across the stream in order to account for lateral variations in depth. Each group is asked to share their results with the class, but must come up with their own way of communicating their results. (NC State, p. 8-9)	Using a map with two modern stream systems, students are told to sketch a series of maps that show the progressive changes that will occur as erosion continues around some of the map's features. (Zumberge, p. 114-115)	None identified.

Table 4 (continued)

	Level of Inquiry			
	Confirmation	Structured	Guided	Open
Groundwater	<p>Students are given a table of subsidence by year and asked to calculate the total subsidence for a given time range. (AGI/NAGT, p. 289)</p>	<p>Using the relationship of flow lines to water table contours, students sketch a network of flow lines on a map. Students are told how to represent these lines on the map, but results are not immediately obvious. (Zumberge, p. 130-131)</p>	<p>Based on the flow lines drawn (see Structured example), students determine whether there is reasonable evidence to conclude whether seepage from a dump contaminated a well. (Zumberge, p. 130-131)</p>	<p>Students are given a case involving a dispute between a farmer and two local companies whose pumping he suspects are responsible for his wells running dry. The students act as consultants to determine why the farmer’s wells have run dry based on depth to water data before and after commercial pumping. (Ludman and Marshak, p. 293-294)</p>

3.3 Results

3.3.1 What do the levels of inquiry look like in Physical Geology labs?

Each Physical Geology lab evaluated contained at least two different levels of inquiry, typically Confirmation and Structured (Figure 2). Most (20 of the 24) of the labs contained at least one Guided inquiry exercise and all labs contained some Structured activities. With two exceptions (NC State's Earthquakes and Plate Tectonics labs), all of the lab topics contained some amount of Confirmation activities. Only three labs contained Open inquiry activities. The average proportion of exercises at each level of inquiry in these four lab manuals was: 34.5% Confirmation, 45.1% Structured, 17.9% Guided, 2.4% Open. This produces an inquiry score of 45.3.

There was a statistically significant difference between the inquiry scores assigned to the activities in the different lab manuals ($H(3) = 22.694, p < 0.0001$) (Figure 3). Average inquiry scores by manual were 70.1 (NC State), 44.4 (Ludman and Marshak), 35.8 (AGI/NAGT), and 31.1 (Zumberge). Post hoc paired comparisons revealed that inquiry scores for the activities in the NC State lab manual were significantly higher than those of the other three lab manuals ($p < 0.0001$). The remaining lab manuals do not differ significantly from each other.

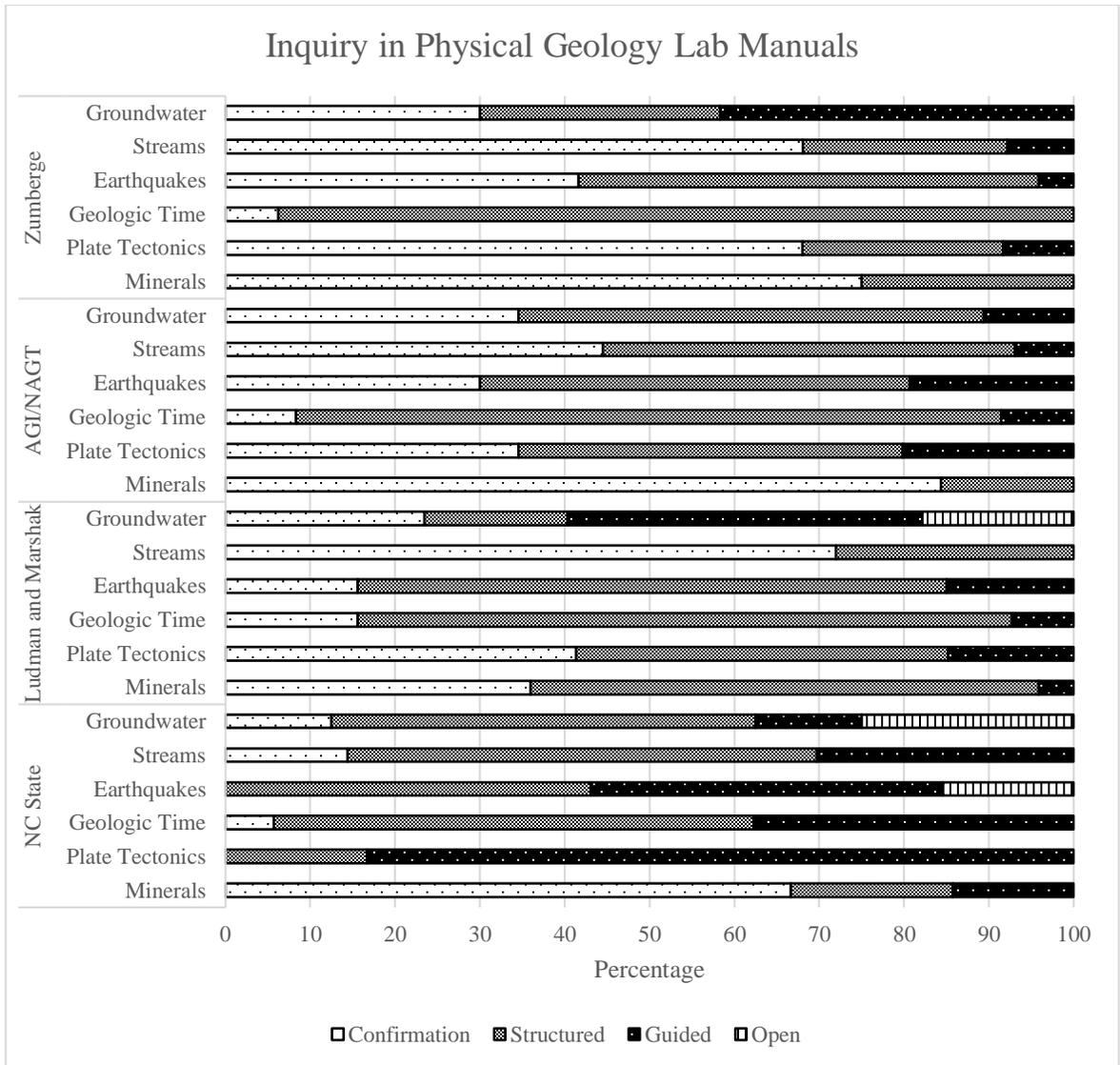


Figure 2 Proportion of each lab analyzed that can be attributed to each level of inquiry. No Authentic Inquiry activities were identified in any of these labs.

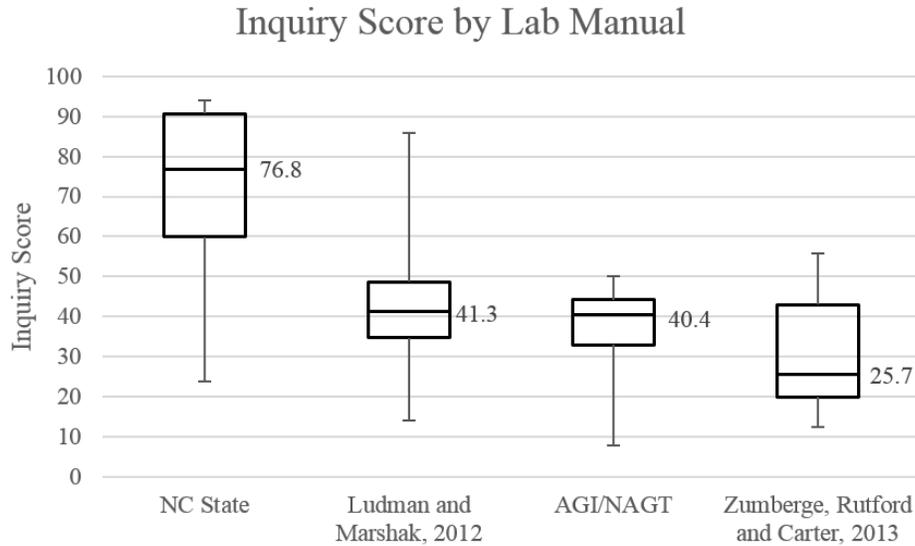


Figure 3 Range of inquiry scores for each of the four lab manuals analyzed. Numbers represent median scores. Inquiry scores for the NC State lab manual were significantly higher than the other three lab manuals at $p < 0.0001$.

There was also a statistically significant difference between the inquiry scores assigned to the activities in the different lab topics ($H(5) = 28.846, p < 0.0001$) (Figure 4). Post hoc paired comparisons revealed statistically significant differences between several of the labs (Figure 5). Specifically, activities in the Minerals and Streams labs received significantly lower inquiry scores than those in the Geologic Time, Earthquakes, and Groundwater labs. The activities in the Minerals lab were also significantly lower than those in the Plate Tectonics lab.

The average inquiry scores for these two low scoring lab topics were 19.55 for Minerals and 30.77 for Streams. These labs were characterized by predominantly Confirmation and

Structured Inquiry exercises (Figure 4). Few Guided activities were identified in these labs. The lab topic with the highest average inquiry score was Groundwater (66.84; Figure 4). The Groundwater labs had the highest percentage of Open activities of all the lab topics (10.7%; Figure 2).

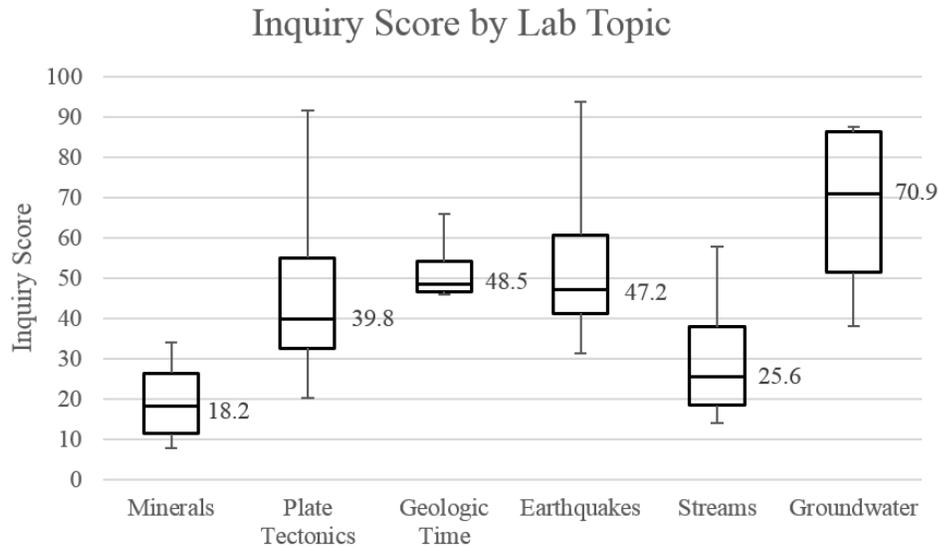


Figure 4 Range of inquiry scores for each of the six lab topics analyzed. Numbers represent median scores.

	Minerals	Plate Tectonics	Geologic Time	Earthquakes	Streams	Groundwater
Minerals		*	**	**		**
Plate Tectonics	*					
Geologic Time	**				**	
Earthquakes	**				**	
Streams			**	**		*
Groundwater	**				*	

Figure 5 Matrix displays statistically significant differences between activities in different lab topics. A single asterisk (*) denotes a difference at $p < 0.05$. A double asterisk (**) indicates $p < 0.001$.

3.4 Discussion

Ideally, what levels of inquiry would we want to see in Physical Geology laboratory manuals, and what does this mean for geology lab development? As scientists and instructors, it would seem that we would like students to develop a mix of both technical skills (such as map reading or mineral identification) and scientific reasoning skills (such as interpreting the geologic history of an area from a cross section) in labs. A mix of inquiry levels is one way to address this. However, most of the activities identified in the Physical Geology lab manuals are lower inquiry activities, which do less to support the development of scientific reasoning skills.

3.4.1 Scaffolding inquiry based on concepts to be learned

The higher inquiry scores in the NC State Physical Geology labs are a result of a higher number of activities at the Guided and Open level, though these are paired with Confirmation and Structured level activities. It is not recommended that all activities should be at high levels of inquiry, as this can cause students frustration (Deters, 2005; Volkmann and Abell, 2003). For example, students may not be ready to formulate their own questions or establish experimental controls at the beginning of a semester. However, by starting out at lower levels of inquiry and increasing the level of student independence over time, students can be made to feel more comfortable taking control in the lab environment. In describing how instructors might vary levels of inquiry over time, Fay and Bretz (2008) proposed four possible inquiry trajectories featuring slow, rapid or linear increases, as well as an oscillating level of inquiry. The strategy used in the NC State Physical Geology labs most closely matches the oscillating

level of inquiry by concentrating lower level inquiry activities at the start of each lab and building to the higher level activities by the end of the lab. This increasing process is repeated from week to week in lab. The Confirmation and Structured activities in these labs are often set up to scaffold the student towards the higher inquiry levels, much like how lower level questions on Bloom's taxonomy may scaffold a student's ability to answer higher order questions (Eick et al., 2005). We suggest that lower level inquiry exercises should be used to help students master descriptive topics (Lawson et al., 2000a; Lawson et al., 2000b; Timmerman et al., 2008), or to build to higher level inquiry activities that develop higher order thinking skills. For example, mineral identification may be described as a more descriptive, concrete topic. Mineral identification received the lowest average inquiry score compared to the other lab topics. If this is the only skill that we intend for students to get out of this lab, then lower inquiry activities are an appropriate selection. However, if the highest level of inquiry students experience is Structured (as defined by Buck et al., 2008), then they are not learning how to ask their own questions, design their own experiments, and analyze their results. This creates the illusion that geology, and science in general, is about confirming a set of known ideas, rather than creatively investigating how the world works (Herman, 2008).

If the intended purpose of an exercise is for students to master more abstract, theoretical topics or develop authentic scientific reasoning skills, then higher inquiry level activities are needed. For example, the Groundwater labs received the highest average inquiry score of the six topics. The four Groundwater labs analyzed used different activities to get students to

envision how water moves through subsurface materials, an abstract concept that students cannot observe directly. Some labs had students use maps to determine the relationship between the water table and surface feature topography; others had them taking depth-to-water measurements to complete three point problems to determine flow direction. The Open activities in these labs required students to apply their knowledge of groundwater movement to solve hypothetical disputes over groundwater pollution or wells running dry (Table 4). Here, the inquiry level matches the topic being addressed: the higher level inquiry activities support the learning of an abstract concept. The Streams labs also ask students to tackle an abstract concept: how does surface water affect landscapes over geologic time. However, these labs received an average inquiry score closer to Minerals (a descriptive topic) than Groundwater (an abstract concept). If instructors know which labs contain content out of alignment with inquiry levels (low inquiry for an abstract concept; high inquiry for a descriptive concept), it allows them to target those labs for development. This guidance may be especially useful in cases when time and resources are limited for curricular reform.

3.4.2 Increasing the level of inquiry in a Physical Geology lab

While large scale changes take time, some small changes can be readily made to increase the level of inquiry present in Physical Geology labs. To illustrate this, we will use a short example from the Ludman and Marshak Groundwater lab. Though this particular example is a Confirmation inquiry question, the overall lab had the third highest inquiry score of the labs analyzed, so this should not be seen as representative of the lab as a whole. Students are given the following question (emphasis added):

“Are all porous rocks aquifers? Hold pieces of *highly porous pumice and scoria* above two beakers or rest them on the rims as shown in Figure 12.3. Slowly drop or sprinkle water onto the rocks and observe what happens. Are pumice and scoria porous? Permeable? Explain.”

A review of the reading material associated with this activity reads:

“Pumice and scoria are very porous, but their pores are not connected. Pore spaces must be connected for water to move from one to another – a property called permeability.”

Students are given the answer to whether these two rocks are porous by the question itself and the reading beforehand. This is an example of a Confirmation exercise: the correct answer is “immediately obvious from statements and questions in the laboratory manual” (Buck et al., 2008). In order to increase the level of inquiry to Structured, the authors could change the rocks used as examples, remove the “highly porous” descriptor of the rocks in the question, and wait to provide students with the explanation until after the exercise is completed, rather than before it. This would give students the opportunity to learn something that has not already been described in the manual. In order to make this a Guided exercise, the authors could remove the method of analysis (if water moves through the rock, the pore spaces are connected and the rock is permeable) provided to the students. To turn this into an Open inquiry activity, the instructor could still start by providing samples of several different types of rocks, along with the definition for porosity and permeability. They could then ask students to come up with an experiment to put the rocks in order from highest to lowest porosity or permeability, rather than providing them with the procedures.

Multiple resources have been developed with the goal of providing support for instructors who wish to modify their existing labs to include higher levels of inquiry (e.g. Clark et al., 2000; Gooding and Metz, 2012; Grady, 2010; Lott, 2011; Peters, 2005). Volkmann and Abell (2003) lay out ten adaptation principles to guide instructors away from cookbook labs. They report high school teachers have found this easy to use in transforming their instruction. Russell Laboratories (2013) offer five questions to consider for any instructor looking to “un-cook” their cookbook lab, along with examples of phrasing and techniques that instructors can use. The Buck et al. (2008) rubric is not the only one available for instructors (see discussion of other inquiry rubrics above) but it is a straightforward method of classifying and comparing different laboratory activities.

Cognitive skills are not the only area we may wish to develop in Physical Geology labs. Students who have positive experiences with science are much more likely to persist and take a second course in the discipline, improving student retention rates (Brainard and Carlin, 1998; Moskal et al., 2004). Combined with the fact that students often have more personal relationships with their lab instructors than their lecture instructors (Gardner and Jones, 2011), the affective domain cannot be ignored. Asking students to limit themselves to low inquiry activities may influence their views of the nature of science as a primarily confirmatory, fact gathering activity, and negatively influence their perceptions of geology (Herman, 2008).

While asking students to complete higher level inquiry activities from the beginning of a lab may cause frustration, scaffolding those students to the point where they can take on these

activities can lead to a sense of accomplishment, improved theoretical understanding and a view of science as a creative process by which we investigate the world around us.

3.4.3 Limitations

We selected the three published manuals to represent successful publications from multiple publishing companies. The assumption was that these would be reasonably typical of other published geology manuals. However, this may not be the case.

In the NC State lab manual, minerals were grouped with igneous rocks into one lab topic. In the Ludman and Marshak lab manual, minerals were split into two labs: one on identifying minerals on their own, and one showing their relationship to the rock cycle. To allow comparison with the other two lab manuals, we examined only the exercises on mineral identification for the “Minerals” topic. Rocks and the rock cycle were divided up several different ways. The Ludman and Marshak and AGI/NAGT manuals have three separate labs for each rock type, and a separate lab for the rock cycle. The Zumberge manual has one lab on all three rock types. The NC State manual has one lab on minerals and igneous rocks, one on sedimentary and metamorphic rocks, and one on the rock cycle. Because the number of exercises associated with rock identification varied so widely between manuals, we did not choose to use them as a topic in this study.

3.4.4 Conclusions

The benefits of inquiry-based instruction are many, from improving attitudes to maximizing student learning. However, most introductory activities in these Physical Geology lab

manuals were identified as either Confirmation or Structured inquiry activities. The fact that published Physical Geology laboratory manuals incorporate mostly low level inquiry activities (Confirmation, Structured) indicates that inquiry may not be one of the underlying philosophies being used in their development (Siemens, 2002). Activities in the NC State lab manual received significantly higher inquiry scores, showing that it is possible to incorporate higher level inquiry activities in introductory labs. While Buck et al. (2008) showed that levels of inquiry were consistently low (predominantly Confirmation or Structured inquiry) in undergraduate science manuals, we have shown that activities featuring higher levels of inquiry can be readily incorporated in Physical Geology labs as part of the instructional design process.

While some departments utilize published laboratory manuals, many use a style similar to the NC State manual: a mix of activities developed in house with those adapted from other resources. The development of inquiry activities requires time and effort on the part of the person designing the labs. We found the rubric from Buck et al. (2008) straightforward to apply in our analysis, and believe it could be a valuable resource for faculty making decisions about what activities to include in their own labs.

We do not intend to imply that the goal is to offer only higher level inquiry laboratory activities. The level of inquiry should be matched to the task at hand. Higher inquiry level activities are more appropriate for abstract topics. Lower level inquiry activities are more appropriate when the task is descriptive, or to scaffold to higher level inquiry activities. By

providing a mix of high and low inquiry activities in introductory geology labs, students can develop a better understanding of geology and the nature of science.

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Chapter 4 Teaching is Believing: Pedagogical Beliefs, Practices, and Implications for Professional Development

4.1 Introduction

This study examines the connection between reformed classroom practices and teaching beliefs, including personal practical theories of teaching and learning, in geoscience classrooms. A better understanding of the relationship between practices and beliefs could help us understand why the implementation of reformed pedagogies in the geosciences is not more widespread. It could also lead to professional development opportunities that better address the challenges of incorporating reformed teaching strategies in the geoscience classroom.

Reformed, or student-centered, teaching practices emphasize the social construction of knowledge among students and between the students and teacher (Vygotsky, 1978). A student-centered class is typically divided into short instructional segments and provides opportunities for students to work together in small groups to complete formative activities designed to monitor their understanding and assess progress toward well-defined learning objectives. This teaching process is often informally referred to as the “guide on the side” model. Instructional activities can range in scope and complexity, and may include the use of small group discussion (McKeachie, 1972) or Think-Pair-Share tasks (Johnson et al., 2011; Smith, 2000), conceptests (Mazur, 1997), Venn diagrams and evaluation rubrics (McConnellet al., 2003), tangibles and ponderables (Beichner et al., 2007), interactive lecture demonstrations (Crouch et al., 2004; Sokoloff and Thornton, 2004), or lecture tutorials (Kortz et al., 2008). In a reformed geoscience classroom, students use data to justify

positions, experience ambiguity as a result of learning, and learn from one another (Knight and Wood, 2005). Using reformed teaching methods gives students more opportunities to apply scientific knowledge and habits of mind, which makes it more likely for them to retain information (NRC, 2012). Reformed teaching methods are contrasted here against a traditional model (“sage on the stage”) of teacher-centered, instruction that relies heavily on lecture and emphasizes the transmission of information from instructor to students.

4.1.1 Benefits of reformed pedagogy in science classrooms

Numerous studies have reported positive student performance results from the application of research-validated teaching and learning strategies in introductory and majors courses (NRC, 2012). The use of these methods has been shown to improve conceptual knowledge and attitudes in a variety of disciplines from physics (Beichner et al., 2007; Crouch and Mazur, 2001), biology (Freeman et al., 2007; Knight and Wood, 2005; Wood, 2009), the Geosciences (Kortz et al., 2008; McConnell et al., 2006), chemistry (Bowen, 2000; Oliver-Hoyo et al., 2005; Sesen and Tarhan, 2011) and beyond. We will henceforth use the term reformed teaching to refer to these student-centered classroom practices that feature activities that discipline-based educational research has shown to increase student learning (MacIsaac and Falconer, 2002; NRC, 2012). A meta-analysis by Prince (2004) showed broad support for improving learning, promoting student engagement, and addressing misconceptions using reformed practices techniques across all STEM disciplines. Ineffective instruction characterized by dull courses, disengaged instructors, and unsupportive teaching strategies has been cited as one of the principal reasons for undergraduates leaving STEM majors

(Seymour and Hewitt, 1997; Strenta et al., 1994). Positive attitudes toward, and experiences with, science may have a direct bearing on student retention rates, encouraging introductory students to persist and take a second course in the discipline (Moskal et al., 2004; Brainard and Carlin, 1998). Seymour and Hewitt (1997) suggested that a thorough revision of teaching and learning in early science courses would go a long way to retaining a larger proportion of majors.

4.1.2 From traditional to reformed teaching practices

Shifting to the “guide on the side” role and translating research-based teaching strategies to the classroom represents a large hurdle toward reform-based STEM classrooms (National Research Council, 2012), with little evidence of success in overcoming this challenge (Feuer et al., 2002). Instructors often teach as they were taught (Halpern and Hakel, 2002) and may over-estimate the degree to which they have reformed their own classroom. After participating in a workshop on reformed STEM teaching for Biology instructors, observations revealed a discrepancy between what teachers did and what they reported doing (Ebert-May et al., 2011). A majority of instructors reported using specific inquiry-based and student-centered teaching practices on a regular basis. However, observations from video tapes of their lessons revealed that the majority (75%) were using lecture-based, teacher-centered pedagogy, with no major changes in the two years following their professional development experience (Ebert-May et al., 2011). National surveys of science and engineering faculty (Fairweather, 2005; Dancy and Henderson, 2010), and geoscience faculty specifically (Macdonald, et al., 2005), reveal that instructors are likely to rely wholly or

primarily on lecture to deliver content, despite the efficacy of reformed strategies.

In a national survey of physics faculty, Henderson and Dancy (2007) found that while most respondents (87%) were familiar with at least one research-based instructional practice, just under half (48%) reported currently using one. Nearly half of the faculty will discontinue using one of these techniques, suggesting that faculty do not grasp the reasoning behind the practices well enough to adapt them correctly or underestimate issues necessary to deploy them (Rogers, 2003; Henderson and Dancy, 2007). Further, instructors who report using specific strategies vary in their implementation often diverging from the strategy as it was intended (Turpen and Finkelstein, 2009). Other significant challenges to incorporating reformed practices include lack of *peer support* and *time* to develop these practices for their local situation (Fairweather, 2008; Wieman et al., 2010; Austin, 2011) and conflicting beliefs and values related to coverage (Anderson, 2002).

4.1.3 The process of change

Changing to more reformed teaching behaviors is often a slow process, potentially taking several years to reach effective implementation (Pfund et al., 2009). A change in behavior requires an individual to change the way they understand something and develop the appropriate attitude, or a desire to change their actions (Blanchard et al., 2009). That desire to change, sometimes referred to as dissatisfaction or discontentment, is often a driving force behind receptivity to reform (Southerland, et al., 2011; Sunal, et al., 2001). Roehrig et al. (2007) found that teachers who held more student-centered beliefs were more likely to include inquiry-based lessons in their classrooms. Rogers' (2003) theory of the innovation-

decision process outlines five steps that a teacher moves through in adopting a new teaching technique: knowledge, persuasion, decision, implementation and confirmation. During three of those stages, professional development can play a role by providing *access to information* (knowledge), *evaluation data for an innovation* (persuasion) and *assistance in putting it into practice* (implementation).

A change in teaching practices is also promoted through a change in beliefs regarding the teaching and learning process, and the students' role in the classroom. Beliefs influence how teachers respond to professional development (Addy and Blanchard, 2010). Teaching beliefs, or teacher thinking, is argued to be one of the fundamental constructs controlling changes in practice (Woodbury and Gess-Newsome, 2002). Teachers may use different language (verbal expressions) in elucidating their beliefs, despite consistent meaning. Therefore, a framework such as that provided by Luft and Roehrig (2007) is helpful in broadly classifying teacher responses to interview questions into categories for comparison. When deciding how to teach, teachers use their own ideas and attitudes on the nature of science and how students learn (Gess-Newsome et al., 2003). These can be challenged, but unless teachers experience a combination of pedagogical discontentment with their current methods and the self-efficacy to adopt alternative techniques and address the ensuing challenges, their practice will remain the same (Gess-Newsome et al., 2003). Self-efficacy is an individual's belief in their ability to succeed, or be effective, in a given context (Bandura, 1977b). Fortunately, these instructional beliefs are mutable and influenced by both professional and personal experiences (Southerland et al., 2011).

Gess-Newsome and others (2003) proposed a model for the reform of instructional practices based on the Teacher-Centered Systemic Reform (TCSR) model (Woodbury and Gess-Newsome, 2002) and adapted for the college environment (Figure 1). The model incorporates Feldman's (2000) theoretical construct of personal practical theories. Teacher personal practical theories are rules-of-thumb about how the teaching and learning process works based on experience (Feldman, 2000). In order for change in personal practical theories (teaching practices) to occur, teachers must first become discontent with their current practice. If, following a critical intervention, the adapted teaching practices are found to be beneficial and sensible, a new equilibrium is reached and the new personal practical theory is adopted.

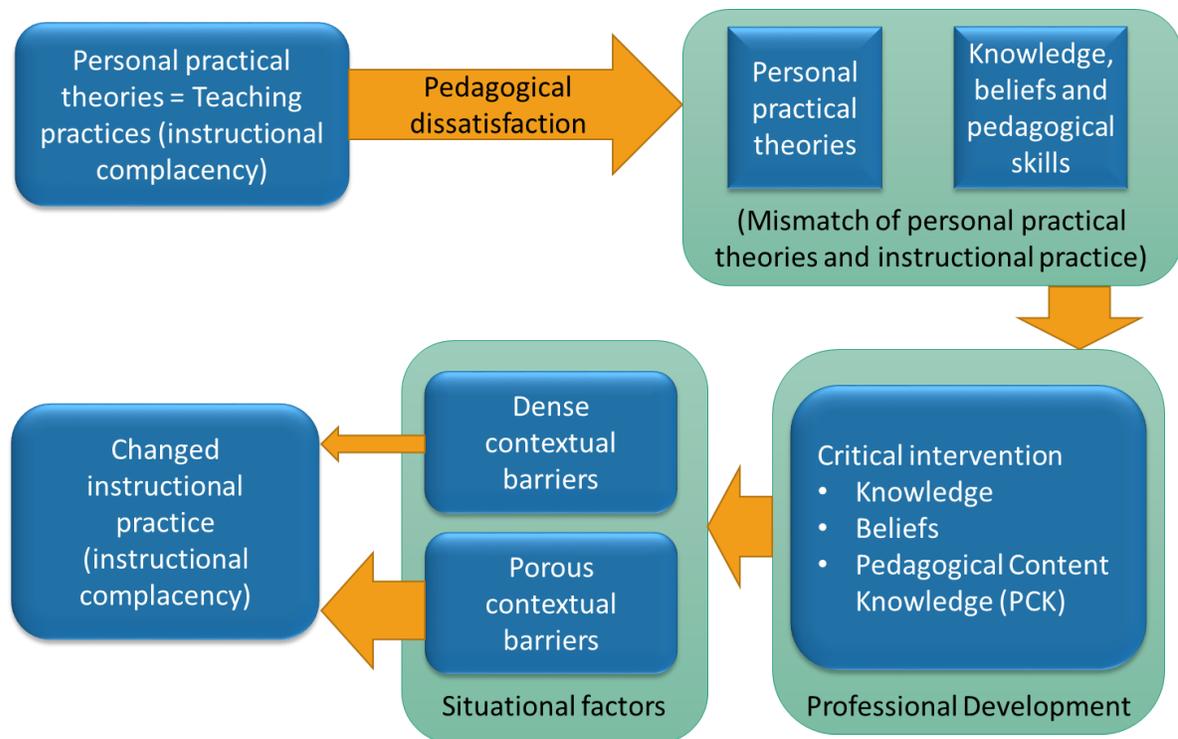


Figure 1 A model for the reform of instructional practices. Adapted from Gess-Newsome et al., 2003

4.1.4 The relationship between beliefs and teaching

Kagan (1992) identified teacher beliefs to be tacit assumptions about situational factors (e.g., student experiences, classroom settings) and course content. Roehrig and Kruse (2005) found that the teaching beliefs of high school chemistry teachers strongly correlated with the adoption of reformed teaching practices. However, Addy and Blanchard (2010) found no significant correlation between an overall measure of reformed teaching practices among biology graduate teaching assistants (GTAs) and their teaching beliefs. However, beliefs were found to correlate with some specific measures such as propositional knowledge (what

the teacher knows, and how well they are able to organize and present material), the quality of student-student interaction and student-teacher relationships. These measures may be more subject to change in lab environments where GTAs are provided materials and told what to teach, compared with procedural knowledge and lesson design and implementation (two other subscales on the observation instrument).

Fang (1996) identified two competing theses on teacher beliefs and practices, focusing on K-12 teachers. He termed these 'consistency' and 'inconsistency' based on whether a strong relationship was found between the two constructs of beliefs and practices. Some researchers (Blanton and Moorman, 1987; Mangano and Allen, 1986; Rupley and Logan, 1984; Wing, 1989) identified a clear relationship between instructional practices and theoretical beliefs, supporting the consistency thesis. Other studies have revealed similar relationships between student-centered beliefs and practices (Luft et al., 2007; Tsai, 2002; Wallace and Kang, 2004)

However, Fang (1996) found that a greater number of studies supported the inconsistency thesis with either mixed results that varied by individual (Davis, Konopak and Readence, 1993; Duffy and Anderson, 1984; Konopak, Wilson and Readence, 1994; Wilson, Konopak and Readance, 1991) or whether teachers were pre-service or in-service (Kinzer, 1988; Readence, Konopak and Wilson, 1991). Fang noted that the inconsistency between beliefs and practices was not surprising. K-12 teachers experience "complexities of classroom life [that] can constrain teachers' abilities to attend to their beliefs and provide instruction which aligns with their theoretical beliefs" (Fang, 1996, p. 53). These complexities include

contextual factors such as classroom management needs, the abilities of students, and school climate. Other researchers have identified additional external factors (e.g. access to resources, limited instructional planning time), teachers' limited or incorrect understandings of student-centered, constructivist instruction, and conflicts with other beliefs as impediments to the consistency thesis (Chen, 2008). Further supporting the inconsistency thesis, Becker and Riel (1999) argued that teachers' beliefs are more student-centered, or constructivist. However, a bureaucratic school culture and public expectations for documenting student achievement severely constrain most teachers from putting those beliefs into daily practice.

Less work has been done on the relationship between beliefs and practices of college instructors. One challenge of observing practices of college instructors is the necessity to cover a large geographic distribution in order to see multiple instructors at different types of institutions teaching the same type of class. Therefore, more research has been done on college instructors teaching beliefs and their intentions regarding practices. This is typically done through interviews and surveys, rather than direct observation the practices themselves (Lumpe, Haney, and Czerniak, 2000; Prosser and Trigwell, 1993; Sampson and Benton, 2006).

Norton et al. (2005) used a questionnaire measuring different aspects of teaching beliefs and intentions of 638 college faculty across multiple disciplines in the United Kingdom. They found an inconsistent relationship, with teachers' intentions being more teacher-centered (focused on knowledge transmission) than their beliefs. Norton et al. (2005) suggested that

this was a result of the academic and social contexts of the different disciplines and institutions, instructor gender, and years of experience.

In a national study of college instructors, Stark (2000) surveyed 2,311 faculty members teaching introductory courses across multiple disciplines, 85% of which were general education courses. Stark found that instructors' beliefs about their students and their discipline strongly influence the way they plan their introductory courses. Contextual factors such as those described above (e.g., student abilities, access to resources, amount of instructional planning time), program or college goals, and literature on teaching and learning and were also found to influence instructor decisions. However, Stark (2000) found that contextual factors are less critical than the instructor beliefs in influencing planning. This may mean that contextual factors act as less of a "filter" creating inconsistencies between beliefs and practices for college instructors compared with K-12 teachers.

It has been argued that changes in teachers' beliefs are necessary before changes in the classroom can occur (Addy and Blanchard 2010; Anderson, 2002; Bandura, 1977b).

However, others have suggested that changes in practices are needed before a change in beliefs can occur (Guskey, 2002). Guskey (2002) reported that it was difficult for professional development programs to initiate changes in attitudes and beliefs without the incorporation of alternative teaching practices. Teachers who were convinced to try an instructional technique and found it beneficial to students were more likely to change their beliefs (Guskey, 1986). This method of professional development requires the teacher both use the technique, and reflect on its efficacy in terms of student learning outcomes (Figure 2).



Figure 2 A model of the process of teacher change. Adapted from Figure 1 from Guskey (2002).

The fact that teacher beliefs may take several years to change (Kagan, 1992) indicates that belief development and classroom practices may be intertwined and the timing of which occurs first may be difficult to untangle or may differ depending on the experiences of the instructors. Beliefs are developed through the “apprenticeship of observation” and culturally transmitted (Lortie, 1975). Teachers have years of experience with educational systems before stepping in front of a classroom as an instructor. Therefore these beliefs will generally endure, unaltered, unless they are deliberately challenged (Gess-Newsome et al., 2003). Belief systems are developed over a prolonged time, so changing beliefs in adulthood is rare (Nespor, 1987; Nisbett and Ross, 1980). When instructors change their beliefs, it is often not through argument or reason, but rather a challenge to contradictions resulting in a “conversion or gestalt shift” (Pajares, 1992, p. 321). These contradictions occur when teachers use traditional methods but have student-centered beliefs, or vice versa. If they are made aware (challenged) that their practices and beliefs are out of alignment, they are more likely to experience that gestalt shift (Pajares, 1992).

4.1.5 Research questions

We sought to investigate the relationship between teaching beliefs and practices among a group of geoscience instructors to better understand how beliefs informed practice or vice versa. The research questions addressed by this study are as follows:

- 1) Where do the teaching beliefs of geoscience instructors plot along a continuum between teacher-centered and student-centered beliefs?
- 2) What is the role of personal practical theories in geoscience professors' beliefs about teaching?
- 3) How do the teaching practices of geoscience instructors vary with their teaching beliefs?

4.2 Methods

This study utilized a mixed-methods approach (Creswell and Plano Clark, 2007), drawing on qualitative and quantitative techniques. Quantitative measures are used to compare the degree to which a classroom is considered reformed and correlate these reformed practices with teaching beliefs. Qualitative field notes from classroom observations and participant responses to semi-structured interviews are used to provide a deeper understanding of the classroom experience and beliefs that may influence that experience.

4.2.1 Observations: Characterizing teaching practices

We used the Reformed Teaching Observation Protocol (RTOP; Sawada et al., 2002) as a standardized means for assessing the degree to which an instructor applied student-centered

teaching practices. We selected the RTOP instrument because it aligned with the principles of constructivism and has well established validity (Piburn et al., 2000; Sawada et al. 2002) and reliability (Sawada et al. 2002; Marshall et al. 2011; Amrein-Beardsley and Popp, 2012). It is one of the most widely used observation instruments in STEM college classrooms, having been employed by many researchers beyond its initial developers. The RTOP instrument has also been used as a standard by which to establish the concurrent validity of newer instruments (e.g., Marshall et al., 2011; Erdogan et al., 2011).

The RTOP describes the degree of reformed teaching in a classroom based on five subscales: Lesson Design and Implementation; Content: Propositional Knowledge; Content: Procedural Knowledge; Student/Student relations; and Student/Teacher Relationships. Each subscale is comprised of five statements ranked using a Likert scale from 0 (Never occurred) to 4 (Very descriptive of the class), for a total score of 0-100. Lower scores indicate a more teacher-centered classroom; higher scores indicate a more student-centered classroom. Typical scores range from 20-80. We used the revised RTOP rubric and protocol as discussed by Budd et al. (2013). Classrooms were visited by a trained observer and all participating instructors were alerted prior to the observation. In addition to the application of the RTOP instrument, observers collected detailed field notes to explain their ratings.

4.2.2 Interviews: Understanding teaching beliefs of geoscience faculty

The Teacher Beliefs Interview (TBI) (Luft and Roehrig, 2007) was chosen to elicit and explore beliefs, as these are often based on unconsciously held assumptions not visible to a classroom observer. The TBI offers a method to gain an understanding of instructors' beliefs

about the teaching and learning process at a given point in time. It is a semi-structured interview with coding maps designed to capture the epistemological beliefs of teachers. The interview consists of seven questions (Table 1), responses to which are coded categorically so as to create a beliefs profile for a teacher.

Table 1 Teacher Beliefs Interview questions

TBI Questions	Notes
How do you maximize student learning in your classroom?	
How do you describe your role as a teacher?	Used “geology teacher”
How do you know when your students understand?	Omitted due to time constraints
In the school setting, how do you decide what to teach and what not to teach?	Omitted due to time constraints
How do you decide when to move on to a new topic in your classroom?	
How do your students learn science best?	Replaced “science” with “geology”
How do you know when learning is occurring in your classroom?	

We used five of the original seven TBI questions, with two being omitted due to time considerations. Interviews were conducted over the phone, and lasted between 15 minutes to an hour. These were audio-recorded and transcribed verbatim without dialect. The responses to each TBI question were then evaluated as described by Luft and Roehrig (2007).

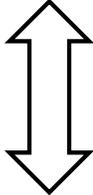
Responses are placed into one of five categories (traditional, instructive, transitional, responsive, and reform-based; Table 2). This was done with a co-coder to establish a Cohen’s kappa value for inter-rater agreement at 0.81, rated ‘good by Cicchetti and Sparrow (1990).

Because instructors may talk about a concept, coding each response requires careful examination of the whole transcript. Once the responses were coded, the author analyzed these for similarities and differences.

In order to compare TIBI scores from our study to those in other studies (in which participants answered all seven questions), we can scale the TIBI scores to be out of 35 rather than 25. For example, a TIBI score of 15 out of 25 in our study would be equivalent to 21 out of 35. This assumes that teachers would have answered the two omitted questions (Table 1) in a manner consistent with their other responses.

Traditional and instructive responses represent teacher-centered beliefs, while responsive and reform-based responses represent student-centered beliefs. Transitional responses represent a midway point that relies on the teacher's role, but involves the student. These coded responses were each assigned a numeric value (1 for Traditional, 2 for Instructional, etc.). This resulted in a possible overall beliefs score (called TIBI by Roehrig and Kruse, 2005) between 5 and 25 for each instructor. Higher scores on the TBI indicate more student-centered beliefs.

Table 2 Criteria used to evaluate responses to Teacher Belief Interview questions.

	Category	Descriptive criteria
Teacher-centered beliefs  Student-centered beliefs	Traditional	Beliefs focus on information and transmission; teacher role is to deliver information.
	Instructive	Beliefs focus on providing experiences, teacher-focus, or teacher decision; teacher organizes instruction.
	Transitional	Beliefs focus on student/teacher relationships, subjective decisions, or affective response; teacher guides students in understanding.
	Responsive	Beliefs focus on collaboration, feedback, or knowledge development; teacher organizes classroom so students can take charge of their own learning.
	Reform-based	Beliefs focus on mediating student knowledge or interactions; teacher modifies instruction based on student learning.

Because teacher beliefs are specific to the educational process, some adjustments were made to the questions to highlight the context being discussed (see Table 1; Luft and Roehrig, 2007). Faculty were asked to answer in the context of the classroom that had been observed. The semi-structured nature of the interview allowed the interviewer to follow up on comments and seek clarification or elaboration of ideas.

4.2.3 Participant selection

College geoscience faculty members from across the country were originally selected to participate based on their willingness to have an observer visit their classroom (Budd et al., 2013). Immediately following the observation, participants were asked whether they felt this lesson was “typical” for the class. An affirmative answer allowed for this observation to be interpreted as reasonably representative of a teacher’s practices. A subset of thirty-five faculty members were selected for follow up with teaching belief interviews on the basis of their wide range of RTOP scores. These faculty members were contacted through three rounds of e-mail requests. A total of eighteen faculty members responded and were interviewed. The sample size was chosen to achieve saturation of ideas and to ensure heterogeneity of the population (Ritchie et al., 2003, p. 84). There is no hard and fast rule for how many people interview in order to reach saturation. The primary concern is that the sample size is “sufficient to enable development of meaningful themes and useful interpretations” (Guest et al., 2006, p. 78). The participants teach face-to-face geoscience lecture courses from across the U.S. They represent a diverse range of experience, institution types, and class sizes taught (Table 3). RTOP scores were not revealed to the author until after the interviews were coded.

4.2.4 Statistical analysis

A Pearson product-moment correlation was used to determine the relationship between an individual’s teaching beliefs (TIBI score) and practices (RTOP score).

Table 3 Demographic data of participants.

Instructor pseudonym	TIBI Score	RTOP Score	Years Teaching	Intro or Majors course observed	Course size	Institution type
Andrew	8	20	Not reported	Majors	10	Baccalaureate
Anna	14	43	8	Intro	220	Masters
Bruce	16	56	1	Intro	33	Baccalaureate
Chris	20	44	1	Intro	100	Masters
Danielle	11	27	13	Intro	220	Doctoral/Research
Elise	13	14	14	Intro	250	Doctoral/Research
Hank	16	22	2	Intro	60	Associates
Ian	16	47	15	Intro	36	Associates
Jacob	14	21	4	Intro	30	Masters
John	19	59	17	Other	60	Doctoral/Research
Laura	19	52	40	Intro	90	Doctoral/Research
Luke	14	35	Not reported	Intro	105	Doctoral/Research
Nancy	18	52	10	Intro	37	Associates
Nikki	15	30	20	Majors	27	Doctoral/Research
Rachel	14	34	22	Intro	82	Masters
Sarah	17	38	2	Intro	160	Doctoral/Research
Stephen	11	33	11	Majors	6	Baccalaureate
Thomas	23	73	3	Majors	19	Doctoral/Research
Average	15.4	38.9	11.4	--	85.8	--

4.3 Results

4.3.1 Observations of teaching practices

Instructors consistently earned the highest marks on the Propositional Knowledge subscale of the RTOP (Figure 3). They presented organized and accurate lessons, made references to material learned in previous classes, and helped students make connections between the

material and the real world. The next highest RTOP subscale score was in Student-Teacher Relationships. For the most part, instructors circulated around the room, welcomed questions throughout class, and had good wait time after giving the class a question. The remaining three subscales (Lesson Design and Implementation, Procedural Knowledge and Student-Student Interactions) varied widely by instructor. The highest scores in lesson design typically represented classes where students have the opportunity to explore the content before a formal presentation, and the content presented was adjusted on the basis of student input on their prior knowledge. In contrast, low scores were characterized by few opportunities for student engagement (e.g. “Does anybody have any questions?”) and limited adjustments to the lesson plan based on student ideas. In order to earn a high score in the Procedural Knowledge subscale, students would use a variety of means (such as drawings or graphs) to represent phenomena, think critically about how they could apply their knowledge, or reflect on how they know what they know. A class that scored low in this subscale is characterized by mostly passive students who are not challenged to make predictions, estimations or hypotheses based on what they have learned. Student-Student Interactions are an indicator of the culture of the classroom. High scores are earned if students have opportunities to share the representations described in the Procedural Knowledge scale with one another at different scales (pairs, small groups, whole class), work on problems with more than one solution, and show respect for their classmates’ points of view. In low scoring classrooms, the teacher’s voice would be the one most often heard with few opportunities for students to interact with one another. See Budd et al. (2013) for more detailed examples of

how these scales can be used to characterize teaching in geoscience classes.

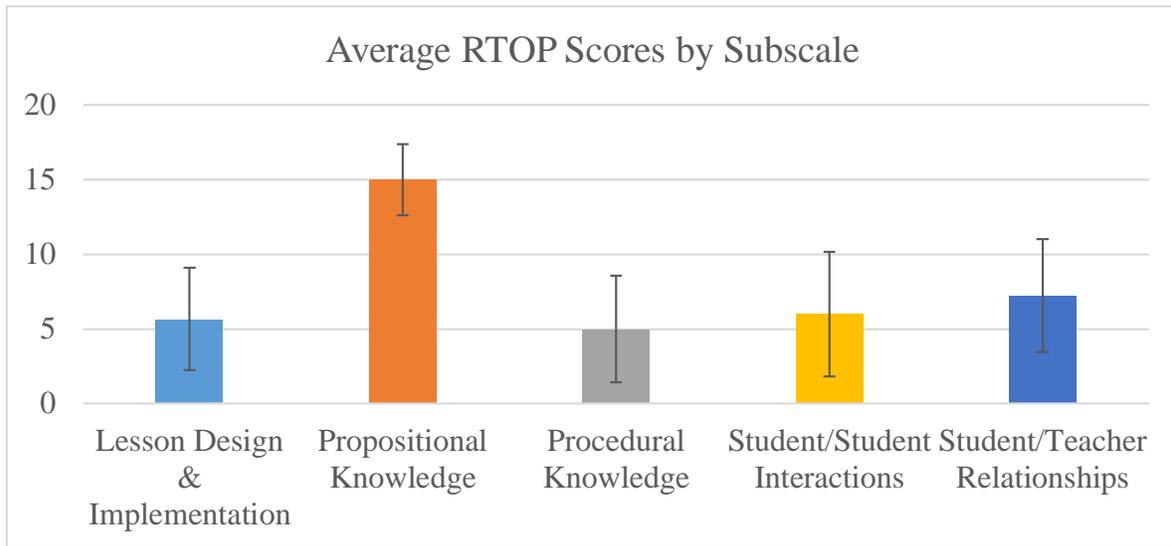


Figure 3 Average scores for all instructors for each of the five RTOP subscales. Error bars represent standard deviation for each subscale.

The relatively small number of study participants prevented a meaningful statistical analysis of the correlation of class size, institution type and years of teaching experience with the degree of reformed instruction. A visual comparison of Table 3 does not reveal any obvious corollaries.

4.3.2 Teaching belief interviews

The average TIBI score (Table 3) for our participants was 15.4 out of 25, with a median response of 3 (Transitional). This would be equivalent to 21.6 out of 35 if all seven questions had been used.

Descriptions of the instructor's role and how students learn science best tended to be more student-centered (Table 4). Instructors discussed how they could draw on student's prior knowledge to build towards a deeper knowledge of the discipline. For example, Chris says his students learn geology best:

“By doing it, I think. If it was up to me, the entire class would be taught in the field or in the laboratory setting where my lecture was in response to questions that [students] formulated through observation. And it's not always easy to do it that way, but we can work towards that goal.”

Chris' answer was Responsive, emphasizing students encountering and interpreting geologic phenomena in different learning environments. The question “How do you describe your role as a geology teacher?” drew more reform-based responses (8 of 18) than any other question.

These responses focus on mediating student's prior knowledge or experiences with the knowledge of the discipline. For example, Bruce describes his role in this way:

“I'm trying to give students a sense of how scientists view the world, or how geologists view the world, and what can be gained through looking at the world through that lens. I'm also trying to get my students to appreciate the role of geology in their everyday life and society. And then I'm also trying to teach them skills, quantitative skills, and writing and observation skills, that are useful for geology, but also would be useful for other careers that they end up going into.”

When asked to describe how they maximized that learning and identified when it was occurring, instructor answers tended to be more teacher-centered (Table 4). For example, Ian emphasized a testing approach when asked how he maximized student learning:

“Numerous assignments...because I have found the more assignments, the more they learn. And we also do fairly frequent evaluations, both with those assignments, [and] also quizzing and testing.”

This was part of a more teacher-centered response that was classified as Instructive. The

teacher maximizes learning by monitoring student actions or behaviors. Ian uses a similar, Instructive approach to determine when learning is occurring. He says, “I read a heck of a lot of stuff...and that includes lab reports, homework assignments, essays, quizzes and tests. So that’s the main thing that I’m using, is those evaluation techniques.” The emphasis here is on the correctness of the student response. By comparison, Nancy offered a Responsive answer to the same question:

“I sometimes wonder around the classroom and listen to their conversations and see if they’re on track. I use clickers and so I can ask them questions and see if they can answer them. By the questions that they ask me, you can kind of get a sense of where at least some of them are... [w]ondering around, listening to conversations, answering their questions, helping them if they say they need help.”

Nancy knows learning is occurring when students are able to interact with one another to solve a problem. Responses may be limited or preliminary, but students are able to defend their ideas.

Many (10 of 18) responses to the question, “How do you decide to move on to a new topic in your classroom?” were split between Instructive and Responsive. Responsive answers included an indication of potentially revisiting concepts if students have misunderstandings.

For example, Nancy says,

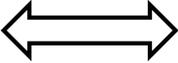
“I figure most of it out ahead of time, but if I ask a clicker question, or students are taking a lot longer on a set of questions than I thought they would, then I would wait and re-do, re-teach something or answer something or you know if a student asked a question that needs clarification, I would spend more time and do that, but and then I would move on.”

Instructive answers were teacher-directed, but included some basic student understanding.

Nikki offered an Instructive response, saying “I mean, some topics I just feel like there’s a

well-defined piece of information/understanding that I want to cover, and it will always take one lecture, and I move on because I've done it."

Table 4 Number of total instructor responses in each belief category by TBI question.

	Teacher-centered beliefs			Student-centered beliefs	
TBI Question	Traditional	Instructive	Transitional	Responsive	Reform-based
How do you know when learning is occurring in your classroom?	0 (0%)	9 (50.0%)	7 (38.9%)	2 (11.1%)	0 (0%)
How do you maximize student learning in your classroom?	2 (11.1%)	6 (33.3%)	4 (22.2%)	6 (33.3%)	0 (0%)
How do you decide when to move on to a new topic in your classroom?	4 (22.2%)	5 (27.8%)	2 (11.1%)	5 (27.8%)	2 (11.1%)
How do your students learn geology best?	1 (5.6%)	4 (22.2%)	2 (11.1%)	7 (38.9%)	4 (22.2%)
How do you describe your role as a geology teacher?	1 (5.6%)	2 (11.1%)	5 (27.8%)	2 (11.1%)	8 (44.4%)

4.3.3 Statistical analysis: relationship between practices and beliefs

The Pearson product-moment correlation revealed a statistically significant ($r(16) = 0.780$, $p < 0.0005$) relationship between an individual's teaching beliefs and practices (Figure 4). This indicates a strong, positive relationship between beliefs and practices (Hinkle et al., 2003). The correlation coefficient (r^2) indicates that 60.82% of the variance in total RTOP score can be accounted for by knowing the TIBI score, or vice versa.

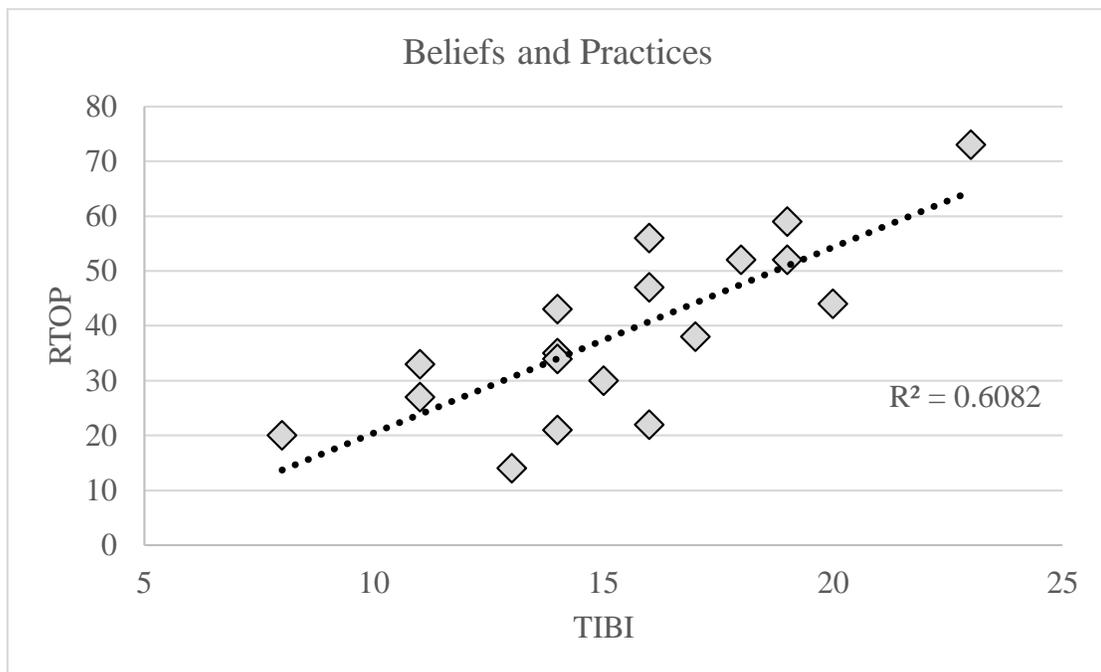


Figure 4 Relationship between beliefs and practices. Higher TIBI scores indicate more student-centered beliefs. Higher RTOP scores indicate more student-centered practices. The one-tailed p value is < 0.005 .

4.3.4 Cross-Case Analysis: Sage on the Stage vs. Guide on the Side

Below, we compare answers to TBI questions for four instructors: Laura, John, Danielle and Jacob (Table 5). These participants were chosen to represent examples of the “sage on the stage” and “guide on the side” models of teaching practice, and to highlight differences in their personal practical theories. “Sages” were identified as instructors who had both low TIBI and RTOP scores compared to the rest of the participants, representing more teacher-centered beliefs and practices. “Guides” had high TIBI and RTOP scores, representing more student-centered beliefs and practices.

Table 5 Beliefs and practices for four geoscience instructors

		“Sage on the Stage”		“Guide on the Side”	
		Jacob	Danielle	Laura	John
Practices	RTOP Score	21	27	52	59
Beliefs: TBI Questions and responses	How do you maximize student learning in your classroom?	3: Transitional	2: Instructive	4: Responsive	4: Responsive
	How do you describe your role as a geology teacher?	2: Instructive	3: Transitional	5: Reform-based	5: Reform-based
	How do you decide when to move on to a new topic in your classroom?	4: Responsive	3: Transitional	2: Instructive	3: Transitional
	How do your students learn geology best?	2: Instructive	1: Traditional	5: Reform-based	4: Responsive
	How do you know when learning is occurring in your classroom?	3: Transitional	2: Instructive	3: Transitional	3: Transitional
	TIBI Score		14	11	19

Sage on the Stage: Low TIBI, low RTOP

Danielle and Jacob had similar TIBI scores of 11 and 14, composed of mostly instructive and transitional responses (Table 5). Though their overall scores were similar, their responses to individual questions all differed by one category. Danielle was teaching 220 students in Historical Geology, Jacob had 30 students in an Earth Systems Science course. Despite the difference in class sizes, Danielle and Jacob's RTOP scores were within six points of each other, with Danielle receiving a slightly more student-centered score.

Danielle's goals for the course were to "expose them to science in a way that they may not have been introduced to it in the past, but also give them an understanding of what science means in their life". In answer to the question, how do you describe your role as a geology instructor? Danielle said:

"My role as an instructor is to, first of all, engage them in the science content. To try to give them some personal relationships with the material that we're going over. I show a lot of photographs, tell some stories that might help them better to relate to the content...[I] ask them questions as we're going through the lecture and get student responses. So there's a little bit of instructor-led discussion that may become somewhat student discussion on occasion, but I would say it's more instructor-led discussion."

Danielle wants the course to engage students (Transitional), but in the classroom observation, she missed out on opportunities to have students apply their own knowledge to features of interest. Her comments about using predominantly instructor-led discussion are reflected in Danielle's low student-student interaction subscale score on the RTOP. Her class is predominantly lecture, with few or no opportunities for students to interact with each other.

In describing his role as a geology teacher, Jacob said,

“It might be pretentious of me, but I think a lot of teachers think of themselves as at least trying to achieve information in the students, so I try to take a science class and make it exciting enough to where my students are actually actively trying to learn in a class as opposed to just sort of dozing off. So I try to make science more accessible.”

Jacob focuses on providing information to the students by focusing on providing an

“exciting” experience (Instructive). His personal practical theory here is that excitement is a necessary component of a classroom in which students will learn. It was evident from the observation that students respected and liked instructor. He believes he views his role differently than “a lot of teachers” do, and that his use of more student-centered language might make him sound pretentious.

The observer noted that students responded to instructor questions through shout outs, which was more than what had happened in Danielle’s class. Students listened attentively and took notes throughout the lecture, but did not interact with one another. Both instructors see their role primarily as someone who delivers information through lecture, with a smaller portion as either discussion leader (Danielle) or advocate (Jacob).

Instructors with more teacher-centered beliefs are more likely to emphasize lecturing and other traditional instructional practices. When asked how students learn science best, both Danielle and Jacob commented that it varies from student to student, and raised the issue of visual, auditory and kinesthetic learners. That students have different learning styles represents a personal practical theory of how students interact with course material, and can influence the type and variety of activities a teacher may use in its presentation. For example,

Jacob uses this as a rationalization to break away from lecture and get students excited by presenting them with different information.

“I think most students seem to be visual or haptic. I think auditory learners are a dying breed right now. It seems like most people can’t seem to concentrate for that long. So, because of that, my lectures are broken up. I pass around lots of samples, I have them get up and look at maps. I try to get them out of their seats as much as possible. I try to make it as hands on as possible, which is *fairly* easy for a geology class. You can show them rocks, and show them lots of pictures.”

These “sage on the stage” instructors incorporate carefully selected images (visual) and give thoughtful lectures (auditory) in their classrooms. However, they do not ask their students to do much besides sit passively. When asked for examples of haptic or kinesthetic learning activities, Danielle included shouting out short answers and answering test questions. These would be more appropriately described as assessment rather than learning activities and as verbal rather than kinesthetic tasks. Jacob included passing around rocks or looking at pictures and maps; however, from the description it is not clear that students are being asked to do much with them. Missing opportunities like having students compare interpretations of these materials is one reason that Jacob plots below the trendline in Figure 4.

Guide on the Side: High TIBI, high RTOP

Laura and John both scored a TIBI score of 19, with more responsive and reform-based responses. John had a slightly higher RTOP score than Laura (Table 5). They were both teaching second semester geology courses: John had 60 students, Laura had 90. Both Laura and John have far more student-centered answers to questions regarding their role in the classroom and how students learn science best.

Laura's goal for the class is for students to learn and enjoy it.

“I don't want them to memorize, regurgitate on the exams and then wipe their slate clean for the next semester's courses. I want what they learn in this one semester intro geology course to stay with them and be available to them at, and give them enjoyment, for the rest of their lives, wherever they may travel.”

She sees herself wearing a lot of hats in the classroom, including

“a facilitator, a motivator, a modeler of how a scientist approaches a problem, and seeks to find answers to it, a motivator in terms of being enthusiastic about a subject that almost no one has been exposed to in high school and has no idea really as a science... a coach to think more clearly about and practice verbalizing and understanding of complex concepts and processes. A motivator also for kids to pay more attention to and actually see the world around them. And practice putting the textbook, classroom, laboratory learning that they've done by going out in the real world and actually practicing it...I am *not* a textbook. I am not a pitcher trying to pour knowledge into little gaping mouths.”

This role goes far beyond the simpler lecturer and discussion leader of the “sage on the stage” model. In describing her role, Laura puts an emphasis on the outcomes of her actions.

It is not enough for her to model the scientific process, but she wants her students to model it as well. John also mentions this idea of a motivator in describing his role.

“I feel like my role as an instructor there is to really motivate that group of students to be excited about learning [the content]. And I need to do that with a group that has sort of mixed abilities and mixed interests.... So, my big view here is I'm trying to do sort of two things: engage across the audience, and at the same time produce some sort of critical thinking and quantitative things for the students who are pursuing the earth sciences.”

Instructors with more student-centered beliefs are more likely to incorporate inquiry-based, active learning teaching techniques in their classrooms. While Danielle and Jacob talked about some students being kinesthetic learners, Laura and John place a high value on problem solving as one of the best strategies that helps students learn science. These

represent different personal practical theories for how students learn.

Laura: “I give them geologic maps to interpret as parts of labs and homeworks...I’ve tried to incorporate a few more case studies or at least more real world examples of applications of most of the topics that we go through so that they do see it as a connected real world science.”

John: “I think one of the ways to learn science is to do things like these problem sets. It’s one thing for me to prattle on as an instructor. It’s another thing to give an hour exam, where you have all these time pressures that I think may preclude sort of student achievement. So I think it’s very important to give these problem sets which are sort of quantitative, very much problem solving, critical thinking, and I encourage people to sort of work together at some level.”

Whereas Jacob talked about having his students look at maps, Laura talks about students using them as part of case studies, which would be a more appropriate kinesthetic learning activity. In John’s class, students were often called on by name, volunteered questions, and worked in small teams on a problem set for a prolonged period of time. Laura’s class included field images, animations, and breaking out in small groups to create concept sketches.

4.4 Discussion

4.4.1 Where do the teaching beliefs of geoscience instructors plot along a continuum between teacher-centered and student-centered beliefs?

One of the research questions we sought to answer with this study was, where do the teaching beliefs of geoscience instructors plot along a continuum between teacher-centered and student-centered beliefs? TIBI scores varied a great deal by participant (Table 3), with some instructors being much more teacher or student centered than others. They also varied by question (Table 4), with descriptions of the instructor’s role and how students learn

science best being more student-centered. Instructors were more teacher-centered in describing how they maximize student learning and identify when it is occurring in their class.

The average TIBI score scaled to be out of 35 was 21.6 for all participants. This is comparable with average TIBI scores from other studies. Addy and Blanchard (2010) interviewed eight Graduate Teaching Assistants (GTAs) teaching introductory life science course and enrolled in a teacher certificate program at a large, doctorate-granting university. They found an average TIBI score of 18.75. Luft et al. (2011) found an average TIBI score of a little over 17 (estimated from Figure 2 in Luft et al, 2011) for 95 beginning secondary science teachers. We were surprised that geoscience instructors' beliefs were reasonably comparable with participants in these studies, given that most geoscience instructors have not received formal educational training like the teacher certificate or licensure programs. It is unclear whether this is due to training in other professional development programs, or a feature that is inherent to the geosciences.

4.4.2 The relationship between beliefs and teaching

The TBI interviews allowed us to triangulate and justify interpretations made during classroom observations, explaining why the participant teaches the way they do. A strong, positive relationship was identified between geoscience instructors' teaching beliefs and reformed teaching practices based on the TIBI and RTOP scores. This supports the hypothesis that instructors with greater reformed teaching beliefs exhibit more characteristics of reformed teaching in their classes that incorporate active learning teaching strategies.

Instructors with more teacher-centered beliefs are more likely to utilize instructional practices that emphasize information delivery.

The strength of the relationship between geoscience instructor beliefs and practices supports the consistency thesis put forth by Fang (1996) and observed in some K-12 classrooms (Blanton and Moorman, 1987; Mangano and Allen, 1986; Roehrig and Kruse, 2005; Rupley and Logan, 1984; Wing, 1989). The relationship between beliefs and practices appears to hold regardless of institution type, years of teaching experience or class size. This may mean that contextual factors act as less of a “filter” creating inconsistencies between beliefs and practices for college instructors compared with K-12 teachers. This is similar to the results of Stark (2000), who found that contextual factors were less important than beliefs for faculty planning how to teach introductory college courses.

This is not to say that external factors (as identified by Norton et al., 2005) are not playing a role. Indeed, several instructors commented that they are unable to teach in a manner that aligns with their beliefs. For example, Chris’ comment about “If it was up to me, the entire class would be taught in the field or in the laboratory setting” indicates that his practices and beliefs are out of alignment due to factors outside his control. His personal practical theory is that students would learn geology best by experiencing it in a more natural setting than the lecture. However, due to time constraints and class size, this option is not available to him.

In their model, Gess-Newsome et al. (2003) show instructor’s personal practical theories about teaching and learning as a filter for the reform of instructional practices. An

instructor's personal beliefs will determine how their teaching practices will change over time based on pedagogical dissatisfaction, professional development and situational factors. Situational factors described by instructors included class size, planning and instructional time, and availability of physical resources, like access to field sites. Whether these represent dense or porous barriers as described by Gess-Newsome et al. (2003) is dependent on the individual's situation and how critical the barrier is to implementing instructional practices. For example, class size and instructional time represent a dense contextual barrier for Chris' belief that classes should be taught outside or in the lab. However, this belief does not seem to be strong enough to cause Chris a great deal of pedagogical dissatisfaction (Figure 1). For Laura, who also argues that students learn best by connecting what they're learning in class to the real world, her similar class size (90 vs. 100) represents a more porous contextual barrier that she can work around by including case studies and maps in lab and homework exercises.

4.4.3 Implications for professional development

One factor noted by several participants as influential in the development of their beliefs or practices, or changing personal practical theories, was the amount of time or effort engaged in professional development. Professional development could include workshops or webinars, or exploration of alternative curricular resources, such as those provided by Science Education Resource Center (SERC, <http://serc.carleton.edu>). When asked for final thoughts on what shaped his teaching practices, Thomas said:

“I would say that [a colleague] had advised me to go to the [On the Cutting Edge]

early career workshop for geosciences... And that helped a significant amount. It just gives you tools for when I want to break up [lecture], when I see eyes dropping and I need to wake them up again, a lot of tools I learned at that conference helped significantly. Just little timing techniques.”

Professional development is not limited to “one shot” experiences, but could also include interactions with members of the immediate community, such as a departmental peer who is also trying to include active learning techniques in their classroom or a chair who values innovative teaching techniques. Andrew expressed concern that his students had difficulty understanding what he was asking on his test questions, despite incorporating some new teaching techniques. The test questions integrate concepts learned over several weeks. His colleague raised the idea of Bloom’s taxonomy, and

“I would say that, on a Bloom’s taxonomy, probably 75% of my tests are on the synthesis-side of things. And I, it’s something I hadn’t really thought through, it’s just the way I’ve always tested, and especially writing something.”

Had he not realized he was not scaffolding students to reach the synthesis level of Bloom’s, Andrew may have unfairly blamed the new teaching practices. Beliefs and practices are developed through the apprenticeship of observation (Lortie, 1975). Instructors seek out professional communities that they identify with, and are encouraged to change by them.

When designing professional development opportunities to increase student-centered teaching in the geosciences, leaders can take advantage of the trends seen by question on the TBI. In this study, instructors’ descriptions of their role and how students learn science best tended to be more student-centered. If their ideas are already more student-centered, time is better spent discussing specific instructional strategies to increase the degree of reformed instruction taking place. Instructors may need more help understanding how to maximize

student learning and know when it is occurring in a student-centered manner. It is possible to accelerate changes in classroom practices if we can help teachers modify and understand (make explicit) their beliefs. Epler (2011) recommended that teacher educators identify beliefs of teachers, and facilitate interventions to modify them if their practices and beliefs are out of alignment with each other. These interventions would challenge teachers to be explicit about their teaching beliefs during professional development. Engaging in this metacognitive reflection makes it more likely that teachers will make changes to their teaching beliefs (Brownlee et al., 2001; Epler, 2011). Professional development that has been successful at altering teachers' core beliefs addresses the teacher as a learner and involves the teacher in praxis: doing, reflecting, learning, changing (Peterman, 1991).

4.4.4 Which comes first: beliefs or practices?

It is unclear from the quantitative data alone which variable changes in response to the other. Models have been proposed showing changes in beliefs preceding changes in practices, as well as changes in practices preceding changes in beliefs (Blanchard et al., 2009; Guskey, 1986; Woodbury and Gess-Newsome, 2002). The qualitative data collected during the interviews informed our understanding of which instructional models were being used by the instructors. This was not a longitudinal study, so we cannot conclude which model is more supported overall. However, it is worth noting that several instructors commented on how they had changed their practices or the way they thought about their role and the way students learn. Some instructors described how their beliefs had changed before their practice, while others described how changing their practices had led to altered beliefs. This

supports the idea that there are multiple avenues to reformed teaching practices (Gess-Newsome et al. 2003; Guskey, 2002).

The semi-structured nature of the interview allowed the interviewer to probe for examples of why those changes had taken place. For example, two instructors, Anna and Elise had very similar TIBI scores and class sizes. However, Anna's class was classified as much more student-centered (Table 3).

In response to the question, "How do your students learn geology best?", Elise responded:

"I wish I could do more hands on, because I really think that sticks. That's the way to do it. But I've always been kind of stumped about how to do more hands on type of activities in a class that's that big. So I'm not really answering your question, or maybe I am answering it, by saying that I think I know how they learn best, but I'm unable to do it, if that's an answer."

This is an example of a situation where a change in beliefs is preceding a potential change in practices. Elise has ideas about how students learn that she is unable to act upon based on class size (250 students). This situational factor represents a dense contextual barrier limiting changes in instructional practice, as shown in Figure 1. She wants to incorporate more "hands on" learning, but needs assistance with how to make that work. The observer noted that this class was lecture-based with only one low-level student activity at the end of class. Elise offered a few convergent questions to the class, and feedback was limited to one or two students. Elise did not act on opportunities to have students discuss more complex, open-ended questions in groups. Because her beliefs are more student-centered than her practices (Figure 4), professional development could target specific strategies for incorporating student-centered, active-learning techniques in large classes.

In response to the question, “How do you maximize student learning in your classroom?”

Anna responded:

“I read a lot of things and I go to workshops and I know there are other tools I could be incorporating into my course. I could be using clickers, I could do stuff like that, but at the same time, I find it... it’s really important that I sort of sense how my room is doing, and...especially in that class, ok in all my classes, I think I have different teaching personas. And it’s really important that the tools I try and use fit that persona, and there are ways in which clickers could actually kind of just shut it down a little bit. Like, what I’ve managed to build in my classroom. So, I try to pick and choose and try new things, and at the same time I try to stick with what I know is working, and that’s like the best I can do, really.”

In Anna’s case, her practices could be preceding a change in beliefs. She plots above the trendline in Figure 4. She already teaches in a more reformed manner than Elise. However, it appears that Anna must change the way she thinks about her classroom before she will adopt any further instructional changes. What she describes as her different “teaching personas” for different class environments represent the intersection of her belief system about how students learn and her own abilities. Without addressing the underlying beliefs, any changes in practices may be temporary and the new technique will be abandoned (Rogers, 2003; Henderson and Dancy, 2007).

4.4.5 Conclusions

If our goal is to make our classrooms more reformed to yield the benefits of increased engagement and retention, it is critical that we understand the relationship between reformed classroom practices and teaching beliefs of geoscience instructors. This study demonstrates that classroom practices are strongly related to geoscience instructors’ beliefs about their role as teachers, how students learn science, and how to maximize that learning. Some of the

variation in this relationship is understood to be the result of different contextual barriers or levels of pedagogical dissatisfaction. A better understanding of these barriers is needed to understand why the implementation of reformed pedagogies in the geosciences is not more widespread. Though the degree to which a geoscience instructor's teaching beliefs could be described as more teacher or student centered varied by individual, as a group, these instructors held beliefs comparable to participants in other studies who were involved in some kind of teacher development program.

As professional development programs encourage faculty to change from traditional, teacher-centered to reformed, student-centered teaching practices, we recommend that they address beliefs as well as practices. Effective change in teaching practices are often preceded by a change in beliefs regarding the teaching and learning process, and the students' role in the classroom. Regardless of whether practice follows beliefs or vice versa, this analysis suggests that we should address both during professional development programs. Further, based on our interview data, we recommend these programs address how instructors can maximize student learning and provide instructors with tools to determine when learning is occurring in their classes. Responses to questions on these topics were more teacher-centered, and changing them is therefore more likely to result in more reformed teaching practices than smaller changes to beliefs that are already more student-centered.

4.5 References

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Chapter 5 Conclusions and Future Work

For decades, many agencies, organizations and researchers have called for science education reform and the incorporation of inquiry-based learning in college classrooms to maximize student achievement and interest (AAAS, 1990; DeBoer, 1991; Novak, 1988; NRC 1996; Schwab, 1962). However, national surveys of STEM faculty, including the geosciences, reveal that instructors are likely to rely wholly or primarily on lecture to deliver content, despite the efficacy of reformed strategies (Fairweather, 2005; Dancy and Henderson, 2010; Macdonald et al., 2005). Labs offer opportunities for smaller groups of students to gain hands on experience with geoscience content, gaining conceptual and procedural knowledge and skills in a more personalized environment (Bybee, 2000; NRC, 1996). In this setting, students typically have opportunities to engage in investigation and inquiry (Hofstein and Lunetta, 1982). However, a review of undergraduate science lab manuals demonstrated that they rely heavily on low, Confirmation level inquiry activities (Buck et al., 2008). Furthermore, GTAs teach the majority of labs at research institutions, and are frequently responsible for instructional decisions, including how information is presented (Luft et al., 2004; Sundber, Armstrong, and Wischusen, 2005; Travers, 1989). This is often done with minimal training or guidance from faculty members (Kurdziel and Libarkin, 2003). Without receiving either instructional materials or guidance that values inquiry-based learning, academic cultural norms will likely encourage GTAs to teach using methods at odds with the calls for educational reforms (AAAS, 1990; Halpern and Hakel, 2002; NRC, 1996; NRC, 2000).

My work in Chapter 2 was motivated by the question of whether GTAs could teach inquiry-based Physical Geology labs in a consistently reformed manner. Using inquiry as a guiding framework, we revised our introductory Physical Geology labs to include multiple inquiry activities. GTAs in charge of these labs were able to teach them in a consistent manner, despite having minimal instructional training. This training was limited to weekly meetings with a lab coordinator to discuss instructional strategies and issues related to classroom management. GTAs who had taught the labs for three or more semesters demonstrated significantly higher in the Propositional Knowledge, Procedural Knowledge and Student-Teacher Relationship subscales on the RTOP than newer GTAs. Experienced GTAs were more likely to make connections between lab topics and the real world or ask divergent questions. They were also more likely to have students develop alternative solutions, question their assumptions, or consider why they were using a procedure. There was a moderate relationship between the RTOP score and degree to which students' grades are accounted for at higher or lower levels of inquiry. This is an important finding for STEM departments looking to incorporate higher levels of inquiry in their introductory labs, and who rely on their effective instruction by GTAs.

Further work in this area is needed to understand the relationship between levels of inquiry and student performance with each of the lab topics. For example, do students develop a different understanding of the nature of science in geology labs that are more or less inquiry-based? How, if at all, do GTA's teaching beliefs change as a result of teaching inquiry-based labs? While student performance is of primary importance, another reason we are interested

in the dynamic of GTAs teaching these labs is as a training opportunity. For most GTAs, this represents their first formal teaching experience. A longitudinal examination of how individual GTAs change their practices over time when teaching high or low inquiry labs could provide insights into whether teaching inquiry based labs serves as an alternative mode of professional development.

Chapter 3 compared the levels of inquiry present in the revised Physical Geology lab manual described in Chapter 2 with three published manuals. The methods in this chapter built on the earlier work of Buck et al. (2008), who used their inquiry rubric to assign a single level of inquiry to an entire lab topic. Our approach broke labs down into activities, and used the proportion of activities at a given inquiry level to calculate an inquiry score for the lab. This allowed for a more fine-grained examination of the labs.

The majority of activities used in the published lab manuals were classified at low levels of inquiry that emphasized confirmation of information that is already known. This indicates that inquiry was not part of the underlying frameworks used in their instructional design. The university laboratory manual contained a significantly higher proportion of higher level inquiry activities compared to the other three lab manuals. These results provide evidence that it is possible, if atypical, to incorporate higher level inquiry activities in introductory Physical Geology labs.

In our analysis, we selected three published manuals to represent successful publications from multiple publishing companies. However, these may not be representative of other published geology manuals. It is currently unclear how many programs rely on published

manuals for the geology labs, and how many develop materials, as was the case with the fourth manual we analyzed. More data is needed to show whether these manuals represent the “typical” Physical Geology lab experience for students.

In introductory labs, GTAs can be provided with the instructional materials they are required to teach with. However, the adoption of reformed, inquiry-based materials in college lecture courses is at the discretion of the instructor. Past research has pointed to teaching beliefs as an important motivator for how instructional decisions are made (Addy and Blanchard, 2010; Blanchard et al., 2009; Gess-Newsome et al., 2003; Luft and Roehrig, 2007; Pajares, 1992; Roehrig et al., 2007). An evaluation of the relationship between classroom practices and teaching beliefs is therefore critical in understanding why the implementation of reformed pedagogies in the geosciences is not more widespread. We identified a strong relationship between classroom practices and instructor’s beliefs about their role as teachers, how students learn science, and how to maximize that learning. These beliefs are broadly categorized under the heading of personal practical theories about how science is both taught and learned. The relationship between beliefs and practices is in line with the consistency thesis originally summarized by Fang (1996) and supported by other researchers (e.g. Luft et al., 2007; Tsai, 2002; Wallace and Kang, 2004). Based on our interview data, variation in the relationship is understood to be the result of different contextual barriers (e.g. class size, access to instructional resources) and levels of pedagogical dissatisfaction. Geoscience instructors held beliefs comparable to beginning secondary science teachers and life science GTAs in a teacher development program (Addy and Blanchard, 2010; Luft et al., 2011).

Based on our results, we recommend that professional development programs trying to encourage geoscience faculty to change from traditional, teacher-centered to reformed, student-centered teaching practices address beliefs as well as practices. Specific topics likely to generate greater change in beliefs and practices are how to maximize student learning and identify when learning is occurring. Other specific recommendations are included in Chapter 4.

The majority of previous work examining the relationship between teaching beliefs and practices has taken place with pre-service and in-service K-12 teachers rather than college faculty members. It is unclear whether our results demonstrating consistency between beliefs and practices would be true for other STEM faculty. However, the strength of the relationship between beliefs and practices in this analysis suggests that both should be addressed during professional development programs if we want to see changes in the pedagogies used by geoscience faculty. Interviews from additional faculty members would allow for further analysis of whether demographic factors such as class size, years of teaching experience, institution type, or experiences with professional development account for any of the variation in the relationship. We could also use a longitudinal study to examine how beliefs and practices change over time, and whether changes in practices are preceded by changes in beliefs, or vice versa. Because little has been done with college faculty members, this topic is a rich area for exploration.

APPENDIX

Appendix 1.1 RTOP Rubric

Lesson Design and Implementation (What Teacher Intended to Do)				
1) Instructional strategies and activities respected students' prior knowledge and the preconceptions inherent therein (what's happened before this class) - A				
Never occurred 0	Lesson is designed to remind students of what they already know and to make use of students' everyday knowledge Inform 1	Lesson is designed to use student input to assess their prior knowledge but not to adjust. Ask 2	Lesson is designed to activate student prior knowledge, assess and adjust content as needed, and makes use of students' input on their prior knowledge Act 3	Lesson is designed to activate student prior knowledge, assess and adjust content as needed, and makes use of students' input throughout the class Maximizes opportunity 4
<p><i>Comments:</i></p> <p>A cornerstone of reformed teaching is taking into consideration the prior knowledge that students bring with them. The term “respected” is pivotal in this item. It suggests an attitude of curiosity on the teacher’s part, an active solicitation of student ideas, and an understanding that much of what a student brings to the mathematics or science classroom is strongly shaped and conditioned by their everyday experiences.</p> <p>Prior knowledge includes both instruction from prior classes and knowledge from everyday experiences. Strategies for referencing prior knowledge include everyday analogies, references to learning from other courses, and references to previous classes in this course. A strong class will activate prior knowledge before initiating relevant instruction, will adjust to prior knowledge levels, and will activate prior knowledge in specific contexts throughout the lesson.</p>				
2) The lesson was designed to engage students as members of a learning community				
No evidence 0	Lesson has limited opportunities to engage students. (e.g., some clickers, rhetorical questions with shout out opportunities, clarification questions) 1	Lesson is designed for continual interaction between teacher and students 2	Lesson is designed to include both extensive teacher-student and student-student interactions 3	Lesson was designed for students to negotiate meaning of content primarily through student-student interaction 4

<p><i>Comments:</i> Much knowledge is socially constructed. The setting within which this occurs has been called a “learning community.” The use of the term community in the phrase “the scientific community” (a “self-governing” body) is similar to the way it is intended in this item. Students participate actively, their participation is integral to the actions of the community, and knowledge is negotiated within the community. It is important to remember that a group of learners does not necessarily constitute a “learning community.”</p>				
<p>3) In this lesson, student exploration preceded formal presentation (students asked to think or do something relevant to new content prior to introduction)-B</p>				
<p>No exploration preceded explanation of new content 0</p>	<p>Exploration precedes new content as a brief learning opportunity that doesn't rely on students using any resources (e.g., what do you think about...) 1</p>	<p>Exploration precedes new content as an active learning opportunity (e.g., using resources provided by instructor), no more than 10% of class time 2</p>	<p>Exploration precedes new content at the beginning or throughout as one or more active learning opportunities, 10-50% of class time 3</p>	<p>Exploration precedes new content throughout as one or more active learning opportunities, designed to engage students for more than 50% of class time 4</p>
<p><i>Comments:</i> Reformed teaching allows students to build complex abstract knowledge from simpler, more concrete experience. This suggests that any formal presentation of content should be preceded by student exploration. This does not imply the converse...that all exploration should be followed by a formal presentation</p>				
<p>4) This lesson encouraged students to seek and value alternative modes of investigation or of problem solving (questions have more than one right possible answer)- A</p>				
<p>No alternative modes explored 0</p>	<p>Lesson designed for instructor to introduce open-ended questions with multiple correct answers or describe multiple modes of investigation Instructor Tell/Introduce 1</p>	<p>Lesson designed for students to make use of or explore multiple modes of investigation Students Use 2</p>	<p>Lesson designed for students to generate and explore open-ended questions or to generate multiple modes for investigating a question Students Generate 3</p>	<p>The central method of learning in the class is student generation of and exploration of an open-ended problem using multiple modes of investigation. Central focus of class 4</p>

<p><i>Comments:</i> Divergent thinking is an important part of mathematical and scientific reasoning. A lesson that meets this criterion would not insist on only one method of experimentation or one approach to solving a problem. A teacher who valued alternative modes of thinking would respect and actively solicit a variety of approaches, and understand that there may be more than one answer to a question.</p> <p>Modes of investigation refer to different approaches or lines of evidence for address a problem. In a lower scoring class, these are presented to the students by the instructor. In a high scoring class students are actively involved in generating approaches.</p>				
<p>5) The focus and direction of the lesson was often determined by ideas originating with students (is there a clear plan to incorporate student ideas?)</p>				
<p>Lesson is entirely instructor directed 0</p>	<p>Lesson plan accommodates instructor pausing for student questions and ideas 1</p>	<p>Lesson plan call for student generated ideas 2</p>	<p>Lesson plan designed for adjustments based on student input. 3</p>	<p>Lesson plan is entirely student directed, with content guided by instructor, but has allowances for different ideas, and questions 4</p>
<p><i>Comments:</i> If students are members of a true learning community, and if divergence of thinking is valued, then the direction that a lesson takes can not always be predicted in advance. Thus, planning and executing a lesson may include contingencies for building upon the unexpected. A lesson that met this criterion might not end up where it appeared to be heading at the beginning.</p>				
<p>Content: Propositional Knowledge (What the Teacher knows, and how well they are able to organize and present material in a learner-oriented setting)</p>				
<p>6) The lesson involved fundamental concepts of the subject (Is content concept-oriented?)</p>				
<p>No clear focus, just a series of random facts 0</p>	<p>A suggestion of concepts, but not obvious and mostly facts rather than overall concepts 1</p>	<p>Concept taught, but not necessarily within a conceptual framework. Topic is bogged down in term definitions 2</p>	<p>Concepts are presented within a conceptual framework, but still contains miscellaneous details/facts and/or tangents 3</p>	<p>Instructor ties concepts to conceptual framework without any tangential material that potentially confounds 4</p>
<p><i>Comments:</i> The emphasis on “fundamental” concepts indicates that there were some significant scientific or mathematical ideas at the heart of the lesson. For example, a lesson on the multiplication algorithm can be anchored in the distributive property. A lesson on energy could focus on the distinction between heat and temperature.</p>				

7) The lesson promoted strongly coherent conceptual understanding (Presented in a logical and clear fashion—how it's presented; does the lesson make sense, general flow)				
Not presented in any logical manner, lacks clarity and no connections between material and no concepts 0	Lesson is disjointed and not consistently focused on the concepts 1	Lesson is may be clear and/or logical but relation of content to concepts is very inconsistent (or vice versa) 2	Lesson is predominantly presented in a clear and logical fashion, but relation of content to concepts is not always obvious 3	Lesson is presented in a clear & logical manner, relation of content to concepts is clear throughout and it flows from beginning to end. 4
<i>Comments:</i> The word “coherent” is used to emphasize the strong inter-relatedness of mathematical and/or scientific thinking. Concepts do not stand on their own two feet. They are increasingly more meaningful as they become integrally related to and constitutive of other concepts.				
8) The teacher had a solid grasp of the subject matter content inherent in the lesson				
Teacher had no clear understanding of content 0	Teacher has some of the fundamentals, but lesson is still wrought with errors 1	Mistakes are abundant or non-trivial, may promote misconceptions but many fundamentals are sound 2	May have minor mistakes, overall accurate delivery 3	No mistakes, all information presented is accurate. 4
<i>Comments:</i> This indicates that a teacher could sense the potential significance of ideas as they occurred in the lesson, even when articulated vaguely by students. A solid grasp would be indicated by an eagerness to pursue student’s thoughts even if seemingly unrelated at the moment. The grade-level at which the lesson was directed should be taken into consideration when evaluating this item.				
9 Elements of abstraction (i.e., symbolic representations, theory building) were encouraged when it was important to do so (is the instructor using abstractions (representations of phenomena that cannot be observed directly) in a way that scaffolds student development of conceptual understanding)-B				
Teacher uses only text/facts with no opportunities for students to develop conceptual understanding	Teacher uses few elements of abstraction (e.g., diagrams, equations) and not in a logical sequence to develop student conceptual understanding	Teacher uses few elements of abstraction (e.g., diagrams, equations) in a logical sequence to develop student conceptual understanding	Teacher uses multiple elements of abstraction (e.g., diagrams, equations) in a logical sequence to develop student conceptual understanding	Teacher uses multiple elements of abstraction (e.g., diagrams, equations) in a logical sequence to develop and assess student conceptual understanding

Not present 0	Few 1	Few in Sequence 2	Many in Sequence 3	Assess 4
<p><i>Comments:</i> Conceptual understanding can be facilitated when relationships or patterns are represented in abstract or symbolic ways. Not moving toward abstraction can leave students overwhelmed with trees when a forest might help them locate themselves.</p>				
<p>10) Connections with other content disciplines and/or real world phenomena were explored and valued-A</p>				
No connections drawn to real world/other disciplines 0	Some connection to real world/other disciplines made in passing, but not central for content comprehension Not integral to lesson 1	Teacher makes a deliberate effort to connect to real world/ other disciplines, but teacher does all the talking Integral but passive 2	Students participate in making connections to other disciplines/real world phenomena A single set of strong ties is generated Collaborative development 3	Students participate in making multiple connections to other disciplines and real world phenomena in ways that extend their understanding of central concepts A robust network of ties is generated 4
<p><i>Comments:</i> Connecting mathematical and scientific content across the disciplines and with real world applications tends to generalize it and make it more coherent. A physics lesson on electricity might connect with the role of electricity in biological systems, or with the wiring systems of a house. A mathematics lesson on proportionality might connect with the nature of light, and refer to the relationship between the height of an object and the length of its shadow.</p> <p>The goal is to integrate the new knowledge with other learning particularly from other disciplines and to show their application in real world applications/phenomena. The goal is to build ties between students existing knowledge, the new knowledge and real world application.</p> <p>Time invested in assisting students in building a single set of strong ties has more value than developing a large number of weak ties.</p>				

Content: Procedural Knowledge (What students did)				
11) Students used a variety of means (models, drawings, graphs, symbols, concrete materials, manipulatives, etc.) to represent phenomena (variety of means, could also include written interpretation)- B				
Students are not asked to do anything 0	Students use only one means of representing or interpreting phenomena Single Use 1	Students use at least 2 means of representing or interpreting phenomena Multiple Means 2	Students use at least 2 means of representing <u>and</u> interpreting phenomena Representing and Interpreting 3	Students use multiple means of representing <u>and</u> interpreting phenomena Multiple Means, Multiple Uses 4
<p><i>Comments:</i> Multiple forms of representation allow students to use a variety of mental processes to articulate their ideas, analyze information and to critique their ideas. A “variety” implies that at least two different means were used. Variety also occurs within a given means. For example, several different kinds of graphs could be used, not just one kind.</p>				
12) Students made predictions, estimations, and/or hypotheses (PEH) and devised means for testing them- A				
No opportunities for students to make PEHs 0	Teacher may ask class to make PEHs as a whole, only a few students are involved in response, no means for testing Poorly executed 1	Teacher may ask students to make PEHs, mechanism to involve majority of students in generation but no means for testing. Incomplete execution 2	All students are engaged in generating PEHs and engaged in testing to enhance understanding of a central concept. Instructor drives generation of PEH and/or testing. Highly prescribed 3	All students are engaged in generating PEHs and engaged in testing to enhance understanding of a central concept.. Students drive generation of PEH and testing Student driven 4
<p><i>Comments:</i> This item does not distinguish among predictions, hypotheses and estimations. All three terms are used so that the RTOP can be descriptive of both mathematical thinking and scientific reasoning. Another word that might be used in this context is “conjectures”. The idea is that students explicitly state what they think is going to happen before collecting data.</p> <p>A highly scoring class would require that students have the experience of drawing together data, making a prediction, hypothesis or estimation (PEH), and testing the quality of their PEH in a way that enhances their understanding of the central concepts of the lesson.</p>				

<i>13) Students were actively engaged in thought-provoking activity that often involved the critical assessment of procedures (quality) – B</i>				
Students are completely passive 0	Students engage in a single thought-provoking activity, perhaps with prompting for minimal critical assessment of procedure Teacher driven, few opportunities incomplete 1	Students engage in a thought provoking activity combined with a follow on prompting for critical assessment of procedure Complete opportunity 2	Students engage in a single activity that requires critical analysis and synthesis of both content and procedures <i>or</i> in multiple examples of level 2 activities Multiple opportunities or a single complete deep activity 3	Students engage in activities that requires both critical analysis and consideration of where/how students could proceed with new knowledge Student driven, deep, multiple complete opportunities 4
<p><i>Comments:</i> This item implies that students were not only actively doing things, but that they were also actively thinking about how what they were doing could clarify the next steps in their investigation.</p> <p>Critical assessment of procedures:</p> <ul style="list-style-type: none"> - question assumptions - explore next steps - consider why you are using a procedures - evaluate if what you just did makes sense (road check) 				
<i>14) Students were reflective about their learning (what do you think, and how do you know?)-</i>				
A No reflection 0	Teacher sets up at least one opportunity for students to reflect on learning. 1	Teacher sets up some opportunities for students to reflect perhaps with prompts	Teacher sets up multiple opportunities for students to reflect with prompts and assists students in understanding relationship to future learning in some way	Students have pervasive opportunities to reflect with structured prompts that scaffold their ability to leverage learning experiences for future use.

		Absence of scaffolding to leverage learning experiences 2	Partial implementation Not well scaffolded 3	Thorough Ongoing, students practice increasing metacognition 4
<p><i>Comments:</i> Active reflection is a meta-cognitive activity that facilitates learning. It is sometimes referred to as “thinking about thinking.” Teachers can facilitate reflection by providing time and suggesting strategies for students to evaluate their thoughts throughout a lesson. A review conducted by the teacher may not be reflective if it does not induce students to <i>re-examine</i> or <i>re-assess</i> their thinking.</p> <p>We want student to reflect on what they have learned, how they have learned, and on the utility of both these things in further learning (either as content or strategy). Ongoing opportunities for reflection will score more highly, as will structured prompts that scaffold students ability to leverage learning experiences for future use.</p>				
15) Intellectual rigor, constructive criticism, and the challenging of ideas were valued (negotiating meaning/ debating ideas)- D				
Students did not have the opportunity to demonstrate rigor, offer criticisms, or challenge ideas No opportunity 0	At least once the students respond (perhaps by shout out”) to teacher’s queries regarding alternate ideas, alternative reasoning, alternative interpretations. Single query/one response 1	Students participate in a teacher directed discussion of differing points of view and evaluation of ideas Teacher-facilitated discussion 2	Students participate in a teacher-guided but student driven, debate of ideas. Teacher is integral in drawing conclusion regarding evaluation of ideas Teacher-guided group debate/discussion 3	Every student participates in debate of ideas that results in group negotiated conclusion that makes deliberate use of evidence/ arguments to support claims. Negotiated student group debate 4
<p><i>Comments:</i> At the heart of mathematical and scientific endeavors is rigorous debate. In a lesson, this would be achieved by allowing a variety of ideas to be presented, but insisting that challenge and negotiation also occur. Achieving intellectual rigor by following a narrow, often prescribed path of reasoning, to the exclusion of alternatives, would result in a low score on this item.</p> <p>Accepting a variety of proposals without accompanying evidence and argument would also result in a low score. : a variety of ideas, alternative interpretations, or alternative lines of reasoning.</p>				

<p>Classroom Culture: Communicative Interactions (Student-Student Interaction)</p> <p>Communicative interactions in a classroom are an important window into the culture of that classroom. Lessons where teachers characteristically speak and students listen are not reformed. It is important that students be heard, and often, and that they communicate with one another, as well as with the teacher. The nature of the communication captures the dynamics of knowledge construction in that community. Recall that communication and community have the same root.</p>				
<p>16) Students were involved in the communication of their ideas to others using a variety of means and media (variety of types and scales of delivery)- A</p>				
<p>No student interactions – Students asking questions of the instructor or responding individually to questions posed by the instructor does not constitute interaction</p> <p>0</p>	<p>At least one opportunity for student interaction that makes use of a single mode and scale of interaction</p> <p>Single mode 1</p>	<p>Either more than one type of student-student communication, but not at a variety of scales (i.e., pairs, small group, group to group, whole class) or vice versa</p> <p>Not complete 2</p>	<p>Multiple modes and scales are represented in the interactions. They may not be well facilitated or well integrated into the learning experience</p> <p>Complete but not well executed 3</p>	<p>Students have multiple opportunities to interact at different scales using multiple modes. Communication is well facilitated.</p> <p>Comprehensive integration of student interaction</p> <p>4</p>
<p><i>Comments:</i></p> <p>The intent of this item is to reflect the communicative richness of a lesson that encouraged students to contribute to the discourse and to do so in more than a single mode (making presentations, brainstorming, critiquing, listening, making videos, group work, etc.). Notice the difference between this item and item 11. Item 11 refers to representations. This item refers to active communication.</p> <p>The goal of the communication is to increase students’ understanding of central concepts or their skill level on central skills. A high scoring class requires both a variety of modes for students interaction (e.g. brainstorming, problem solving, discussing, presenting, group work) <i>And</i> interactions at multiple scales (e.g. student-student, student-class, whole class). In high scoring classes, communication is well facilitated. The amount of time students spend in interaction is scored below in Q18.</p>				

17) The teacher's questions triggered divergent modes of thinking (by students)- D				
No divergent modes of thinking No opportunity 0	Students listen to teacher present an example of more than one answer or interpretation, but student thinking limited to individual questions about the material. Teacher-sourced divergent modes 1	Students interact in response to teacher-framed question(s) that has/have more than one answer or interpretation, but the directions ask for just one "right" response Student interact/respond to divergent modes 2	Students work on one or more instructor posed problem that has more than one solution, and to generate complete solutions Students actively engaged in divergent mode problems 3	Students work on open ended problems Opportunities provided for students to ask divergent questions of each other and encouraged to pursue alternative solutions- Student-student driven queries of divergent modes 4
<p><i>Comments:</i> This item suggests that teacher questions should help to open up conceptual space rather than confining it within predetermined boundaries. In its simplest form, teacher questioning triggers divergent modes of thinking by framing problems for which there may be more than one correct answer or framing phenomena that can have more than one valid interpretation.</p>				
18) There was a high proportion of student talk and a significant amount of it occurred between and among students (quantity of interactions)				
No student-student talk 0	Students talk to each other at least once (about lesson content) 1	Student-student talk occurs at least 10% of the time during the course of the class 2	Student-student talk occurs more than 25% of the time during the course of the class 3	In any given moment during the lesson, students are more likely to be talking to each other than the teacher (>50% student to student) 4
<p><i>Comments:</i> A lesson where a teacher does most of the talking is not reformed. This item reflects the need to increase both the amount of student talk and of talk among students. A "high proportion" means that at any point in time it was as likely that a student would be talking as that the teacher would be. A "significant amount" suggests that critical portions of the lesson were developed through discourse among students.</p>				

19) Student questions and comments often determined the focus and direction of classroom discourse (quality of student interactions)				
No student input 0	Student conversations are short and limited to “the answer,” no negotiation of meaning 1	Student conversations are brief but do involve some negotiation of meaning 2	Student conversations are in depth examinations of a problem 3	Student conversations are detailed, multi-faceted examinations of recent and previously learned content that is student directed 4
<p><i>Comments:</i> This item implies not only that the flow of the lesson was often influenced or shaped by student contributions, but that once a direction was in place, students were crucial in sustaining and enhancing the momentum.</p>				
20) <i>There was a climate of respect for what others had to say - A</i>				
No ideas beyond instructor are heard Or there is a climate of disrespect 0	Student voices are present and respected Respected 1	Faculty and students volunteer ideas; they respect each others point of view and refer to each others points Used 2	A majority of faculty and students volunteer ideas or their ideas are solicited; they respect each others point of view and refer to each others points Sought 3	Every voice is solicited, heard, respected, and valued. Student talk is critical for success; different points of view are discussed and resolved to enhance learning of central ideas Critical 4
<p><i>Comments:</i> Respecting what others have to say is more than listening politely. Respect also indicates that what others had to say was actually heard and carefully considered. A reformed lesson would encourage and allow every member of the community to present their ideas and express their opinions without fear of censure or ridicule.</p>				

Classroom Culture: Student/Teacher Relationships				
21) Active participation of students was encouraged and valued				
Entirely instructor directed, no student questions 0	Some student questions, may be opportunities to “shout out” ideas 1	Some student questions/ input are encouraged, and they appear to shift the direction of the lesson 2	Many students engaged some of the time in valuable conversations that leads to class discussions that appears to shift the direction 3	All students are actively engaged in meaningful conversation that guides the direction of the lesson from beginning to the end. 4
<p><i>Comments:</i> This implies more than just a classroom full of active students. It also connotes their having a voice in how that activity is to occur. Simply following directions in an active manner does not meet the intent of this item. Active participation implies agenda-setting as well as “minds-on” and “hands- on”.</p>				
22) Students were encouraged to generate conjectures, (or) alternative solutions, and/or different ways of interpreting evidence				
Instructor may present interpretations, conjectures, etc., but asks students to do nothing 0	At least one time, students were asked to consider an alternate solution, make a conjecture, or interpret evidence in more than one way. 1	Teacher-student interactions lead students through a very directed format that considers alternate solutions, and/or conjectures and/or evidence 2	Teacher-student interactions facilitate students through a flexible format that considers alternate solutions, and/or conjectures, and/or evidence 3	Whole lesson is dedicated to students discussing, exploring and critiquing/ considering alternate solutions, and/or different ways of interpreting evidence, with minimal teacher guidance 4
<p><i>Comments:</i> Reformed teaching shifts the balance of responsibility for mathematical of scientific thought from the teacher to the students. A reformed teacher actively encourages this transition. For example, in a mathematics lesson, the teacher might encourage students to find more than one way to solve a problem. This encouragement would be highly rated if the whole lesson was devoted to discussing and critiquing these alternate solution strategies.</p>				

23) In general the teacher was patient with the students (mostly about wait time)				
No opportunity to assess or teacher was not patient (no wait time, answers own questions). Unwanted behavior is tolerated/ ignored 0	There is a bit of wait time after asking a question, instructor avoids answering his/her own questions. Or instructor works with student(s) to clarify their vague question 1	Clear wait time (waiting for multiple student thoughts, waiting for all students have a chance to consider the question; not just taking the first raised hand or “shout out”). 2	Providing some time for student-student interaction (still on task), but may not be enough time for all to achieve goals. 3	Instructor provides adequate time for meaningful conversations to occur between students (enough time to achieve goal) 4
<p><i>Comments</i></p> <p>Patience is not the same thing as tolerating unexpected or unwanted student behavior. Rather there is an anticipation that, when given a chance to play itself out, unanticipated behavior can lead to rich learning opportunities. A long “wait time” is a necessary but not sufficient condition for rating highly on this item.</p>				
24) The teacher acted as a resource person, working to support and enhance student investigations (activity beyond answering a question)- D				
No investigations (activity that engages students to apply content through problem solving) No investigation 0	Very teacher directed, limited student investigation, very rote Rote response to student queries 1	Primarily directed by teacher with occasional opportunities for students to guide the direction Teacher-student co-guidance 2	Students have freedom, but within confines of teacher directed boundaries Student-driven direction of queries 3	Students are actively engaged in their own learning process, students determine what and how, teacher is available to help when needed 4
<p><i>Comments:</i> A reformed teacher is not there to tell students what to do and how to do it. Much of the initiative is to come from students, and because students have different ideas, the teacher’s support is carefully crafted to the idiosyncrasies of student thinking. The metaphor, “guide on the side” is in accord with this item.</p>				

25) The metaphor “teacher as listener” was very characteristic of this classroom- both D				
<p>Teacher was the only “talker”</p> <p>No listening opportunity</p> <p>0</p>	<p>Teacher listened, and acknowledged or validated an idea presented at least once.</p> <p>Teacher listening opportunity (at least once)</p> <p>1</p>	<p>Teacher is listening throughout (from beginning to end), but doesn’t act on any ideas (but does acknowledge)</p> <p>Teacher listens throughout</p> <p>2</p>	<p>Teacher listens from beginning to end of lesson, but doesn’t necessarily act on ideas throughout</p> <p>Teacher listens throughout and acts periodically</p> <p>3</p>	<p>Teacher listens and acts on what students are saying from the beginning to the end of the lesson (from gaining prior knowledge all the way to assessing student understanding).</p> <p>Teacher listens throughout and acts continuously</p> <p>4</p>
<p><i>Comments:</i></p> <p>This metaphor describes a teacher who is often found helping students use what they know to construct further understanding. The teacher may indeed talk a lot, but such talk is carefully crafted around understandings reached by actively listening to what students are saying. “Teacher as listener” would be fully in place if “student as listener” was reciprocally engendered.</p>				