Science Teaching - Dissertations   College of Arts and Sciences

2013

Toward Understanding "Teaching in the Making:" Explaining Instructional Decision Making by Analyzing a Geology Instructor's Use of Metaphors

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ABSTRACT

There is a need to enhance science and geoscience literacy. Effective instruction allows students opportunity to build their own models, test them, make their own arguments, and discern reliability of the claims and arguments of others. Attempts at designing and importing such instruction have shown limited implementation fidelity, even with attached professional development. Up to present, attempts to understand the problem of implementation sought to focused on the context of the teacher (beliefs, knowledges, and motivations) to explain teacher practice, and results indicate great complexity. Maintaining a similar focus, this investigation analyzes a geology instructor's use of metaphor, when talking about teaching, learning, and knowledge, to understand and explain the factors involved in his instructional decision making.

Eric (pseudonym), a geology professor, implemented a curricular intervention in two successive introductory geology classes. However, Eric selected and amended only particular facets of the intervention. The research utilizes classroom observations and multiple audio recorded meetings with Eric to understand why he chose and amended certain parts of the intervention and not others. Results show that Eric described his teaching in terms of two metaphors: the *puzzle metaphor* and the *fieldtrip metaphor*. The metaphors paralleled each other in terms how Eric saw his role, his students' role and the role and the nature of knowledge, and therefore influenced what and how he taught. This study suggests that curriculum designers need to take instructor context into consideration when designing curricular interventions and analyzing for the use of metaphor may be an effective way to discern that context.

Toward an Understanding of "Teaching in the Making:" Explaining Instructional Decision

Making by Analyzing a Geology Instructor's Use of Metaphors

by

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Dissertation

Submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy in Science Education.

Syracuse University

June, 2013

While a student at Syracuse, I have learned a great deal that helped make this dissertation possible. Dr. Sari Biklen started me down the road of qualitative research. Because of her, I will never see my social location the same way again. Dr. Sharon Dotger (my dissertation chair) has fostered my growth from a teacher in an introductory science class to a researcher in that same class. She supported my ideas when I proposed new learning strategies and she was instrumental in helping to re-focus my gaze during this dissertation research. Dr. Jeff Rozelle spent time with me and helped me to flesh out ideas on a number of different projects. He always had time (and a bunch of questions) for me. I learned a great deal from him. Dr. John Tillotson, originally my advisor, is now someone I proudly call friend. He involved me in some of my first research experiences and gave me an opportunity to grow as a research associate on the IMPPACT project. We have had many beers, lunches, and conversations, both professional and personal, together. I have learned much about the workings of the Academy from him. I will also always be grateful for him for officiating at our wedding.

I also want to thank Dr. Monica Young, Dr. Deborah Barry, and (soon to be Dr.) Lauren Jetty (my cohort and friends). I shared office space with these three amazing women and learned a great deal from them (including the challenges and rewards of becoming a mother while in a PhD program) in addition to developing a bond that will endure in the future as we remain colleagues.

I want to thank my committee (most of whom have already been mentioned), Sharon, John, Douglas, and Dr. Suzanne Baldwin. They each helped immeasurably in making this dissertation what it is. Their insights and experience and knowledge helped me along my way and I look forward to sharing future experiences with each of them as I continue to grow as a researcher and teacher. I want to thank the two outside readers, Dr. Tiffany Koszalka and Dr.

Marcelle Haddix. Their insights and comments on this dissertation have helped to make it a stronger piece of research. I also would like to acknowledge that this research was funded, in part, by the School of Education's Creative Research Grant. The grant helped me to purchase an external hard drive for storing my data and backing up everything. I was also able to purchase notebooks for the student participants and other supplies needed for implementing the intervention.

Now, I need to turn to my family, because without them, this dissertation would have very little meaning. My parents, Ray and Beverly, have never wavered in their support of me. Never. They have been there from the very beginning and they have never ceased to remind me how proud they are of me. My best friend, Ben Allio, has helped during all the times I needed just a bit more strength (or beer) to get through. At this point, I acknowledge the two most dear to me. My daughter, May, has been a true inspiration. I know it must have gotten boring for her to have me working on my dissertation (still) for so long. She stuck with me and encouraged me, read to me, hugged me whenever she could, and took my mind off stresses by pulling out a board game. Lastly, I thank my wife, Lu. She walked the fine line between allowing me the freedom of doing what I needed to do, while at the same time not allowing me to be consumed by my work. She has cooked wonderful meals, sat quietly "just being" with me, played piano for me and has been a constant reminder to me of the importance of togetherness. Tim Lowenstein told me once, a long time ago, that having that PhD hanging on the wall does not mean a thing if you do not have someone whose shoulder you could rest your head on. Lu has brought that meaning into my life.

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CHAPTER 1: INTRODUCTION

Opening Statement

This investigation is an extension of my great interest in understanding how people learn, my lifetime love of geology, my recent fascinations with the history and philosophy of science, and the use of metaphor as an indicator of a person's structured thinking. In this introduction, I outline three issues the science education research community identifies as important: 1) the enhanced emphasis on increasing science literacy in the population; 2) the growing importance of geoscience education for facing global geoscience related issues; and 3) the importance of understanding the relationship between an intervention meant to facilitate learning within 1 and 2, and the instructor who implemented the intervention. In this case study, I utilize a metaphor-based analysis to identify why an instructor of an introductory collegiate earth science course made the instructional decisions he did. This research is relevant to the goals of the science education research community because understanding the instructor's decision making can help inform curriculum developers how to enhance teacher effectiveness, which should lead to improved student learning.

Overview of the Dissertation

In this introductory chapter, I briefly describe some issues facing science educators to enhance both geoscience and nature of science (NoS) education and my approach for addressing them. I begin with brief rationales concerning why science literacy and, more specifically, geoscience literacy are important educational goals. I set the stage for the investigation by highlighting another important issue: the factors affecting instructor decision-making while implementing a curricular intervention designed to address the educational goals. This focus is especially relevant based on literature demonstrating the importance of teacher practices on

implementation fidelity (Hulleman & Cordray, 2009), and how teaching practice in Science, Technology, Engineering, and Mathematics (STEM) disciplines is a core factor in determining whether students enter and/or remain in STEM fields through college (Seymour & Hewitt, 1997). I conclude Chapter 1 with a brief description of the structure of the investigation.

Chapter 2 has three parts. The first part describes the general structure of an intervention implemented in the introductory geology classes and builds an argument for the structure of that intervention utilizing literature from studies in the nature of science, geoscience conceptual development, and model-based learning. This literature converges to say that to enhance conceptual development, students must actively engage in the creation of their own knowledge. The second part is a discussion of research concerned with the relationship between instructors and tools for instructional reform. This includes the different perspectives taken for researching the efficacy of instructional reform materials and the instructors implementing them. The third part outlines my theoretical framework for understanding the participant instructor's pedagogical *context* knowledge ($PC_{xt}K$[1]) (Barnett & Hodson, 2001) by analyzing how the instructor participant uses metaphors when talking about teaching, learning and the nature of knowledge.

Chapter 3 outlines my execution of this investigation as the initial stage of a design-based, multi-tiered teaching experiment that occurred at the intersection of the engineered aspects of purely experimental methodologies and the naturalistic and exploratory aspects of qualitative research methodologies. This chapter also explains and demonstrates the coding procedure used to analyze the data. I utilized a grounded theory approach to discern and describe themes that seemed to be influences and motivations of Eric's decision making. I then returned to the data

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[1] This construct of Barnett and Hodson (2001) is broader than and encompasses the common construct, pedagogical *content* knowledge (PCK), first described by Shulman (1986). I use the abbreviation, $PC_{xt}K$, to avoid confusion between the two.

and analyzed it through the lens of Eric's metaphor usage to explain the influences and motivations.

Chapter 4 contains two parts. The first part is a description of the intervention in terms of the activities for students and the more general instructional outcomes. Though the focus of the research shifted from how the students and instructor engage with a historically contextualized curriculum designed to facilitate students' model-based learning to the instructor's decision making, I include this description as a way to provide contrast between what was intended for the research and what actually happened. The second half of this chapter outlines some of the more pertinent examples of Eric's decision making that led to the shift in focus mentioned above.

Chapter 5 outlines the findings from data derived during the intervention period and is broken into three sections. The first section describes six themes (the struggle between structure and student self direction, the certainty of scientific knowledge, teaching with the end in mind, the constraint of time, understanding of the text and understanding of his students) that represent influential facets of Eric's $PC_{xt}K$. Eric made decisions in accordance with these themes; themes that resonate with the findings of others (Banilower, Smith, Weiss, Malzahn, Campbell, & Weiss, 2013; Bartholomew, Osborne, & Ratcliffe, 2004; Höttecke & Silva, 2011; NRC, 2006; Orion & Ault, 2007; Stein, Engle, Smith, & Hughes, 2009). The second part outlines how Eric understood his role as instructor in terms of his authority and responsibilities. These understandings were responsible for motivating his decision making. Part three paints a coherent picture between the $PC_{xt}K$ themes and Eric's motivations within the context of Eric's use of metaphor to understand and explain his decision making during the intervention period.

In chapter 6, I discuss the data and their broader implications within science education research, curriculum design, and teacher development. Of importance is how the instructor

served as a filter between the intended instructional intervention and the one that was realized. Lastly, I discuss the significance of understanding the mechanisms of that filtering process and how developed curricula could take that process into account, but at the same time modify the filtering to better align with research based practices.

The Problem of Science Literacy

We believe that the education of the children of this nation is a vital national concern. The understanding of, and interest in, science and engineering that its citizens bring to bear in their personal and civic decision making is critical to good decisions about the nation's future. The percentage of students who are motivated by their school and out-of-school experiences to pursue careers in these fields is currently too low for the nation's needs. Moreover, an ever-larger number of jobs require skills in these areas, along with those in language arts and mathematics. (NRC, 2012, p. iiiv)

The state of scientific literacy in the US has been a concern for decades. Only about 28% of the nation's adults can be considered scientifically literate (Miller, 2010). This issue is important because a better understanding of the way science works will help the citizenry be better able to evaluate the reliability of scientific claims and therefore be better able to make decisions concerning issues of scientific relevance (NRC, 2012). A quick scan of the headlines in the newspaper will show that many issues facing US citizens are related to science in some way. Many of the decisions that we make are based on what scientists claim about the way the world works. However, there are disagreements. Scientists looking at the same data sometimes send contradictory messages such as the connection between vaccinations and autism or when it is appropriate for women to receive mammograms. Furthermore, there are political or social

interests that can influence how science gets presented (for example, the current debates concerning hydrofracking, recent controversies between teaching evolution and intelligent design, and the current, and heated debate over anthropogenic global climate change). The Board on Science Education (BoSE) (NRC, 2012) stated that "too few U.S. workers have strong backgrounds in these fields [science, technology, and engineering] and many people lack even fundamental knowledge of them" (p. ES 1).

There is a definite need to remedy this science literacy gap. Multiple science education reform documents (AAAS, 1993; NRC, 1996, 1998, 2012; NSTA, 2003) have emphasized the importance of teaching the nature of science (NoS) and scientific practices to students. The Board on Science Education (BoSE) has also made it its goal

> to ensure that by the end of 12th grade, *all* students have some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of scientific and technological information related to their everyday lives; are able to continue to learn about science outside school; and have the skills to enter careers of their choice, including (but not limited to) careers in science, engineering, and technology. (executive summary)

As a means to that end, the *Framework for K - 12 Science Education* (NRC, 2012) contains a list of science and engineering *practices* to help students learn *about* science as opposed to only the scientific "facts." One approach is to incorporate accurate nature of science (NoS) instruction within regular content instruction. NoS refers to the cognitive, social, commercial, cultural, ethical, political, psychological structures interwoven in the process of science (Matthews, 2012). The merits of teaching NoS have been promoted for decades, starting

with Conant (1947). In the 1960s, Gerald Holton, James Rutherford and Fletcher Watson developed curricula supporting such a goal in the form of the Harvard Project Physics, followed soon after by John Moore's and Joseph Schwabb's BSCS Biology course (Matthews, 1994). Others have also written in support of science instruction containing aspects of NoS, including the history and philosophy of science (Allchin, 1997; Bickmore, Thompson, Grandy, & Tomlin, 2009; Justi, 2000; Matthews, 1994, 2012; Rudolph, 2000). For instance, Matthews (1994) stated that teaching the history and philosophy of science (HPS) is important because it promotes better comprehension, is intrinsically interesting, is necessary for learning NoS, counteracts scientism and dogmatism, humanizes the process of science, connects with disciplines within science as well as outside of science, and historical "learning" reflects individual learning about concepts. These claims are largely rhetorical, "common sense" assertions, but there is little empirical data to either support or refute them.

There has been much research done on the teaching NoS to students and its effects on students' or teachers' understandings (often identified as beliefs), or views of the nature of science (VNoS) (Abd-El-Khalick & Lederman, 2000; Deng, Chen, Tsai, & Chai, 2011; Ledderman, 1992, 2007). Not everyone agrees on what to incorporate within NoS instruction. Many have advocated using a consensus list of aspects (Lederman, 2007; McComas & Olson, 1998) whereas recently, others have found a list to be too confining (Allchin, 2011a; Deng, et al, 2011; Matthews, 2012). Researchers have also actively debated best practices to teaching NoS and how to measure students' VNoS (e.g. Allchin, 2012; Schwartz, Lederman, & Abd-El Khalick, 2012).

The Problem in Geoscience Education

Understanding Earth's interconnected systems is vital to the future of our nation

and the world. Ocean and atmospheric interactions effect our daily lives in

multiple, significant ways. Long-term changes in ocean and atmospheric

processes impact national economies, agricultural production patterns, severe

weather events, biodiversity patterns, and human geography. Global warming and

its effects on glacial mass balance, sea level, ocean circulation, regional and

global weather and climate, and coral bleaching, to name only a few potential

impacts, are important global issues that demand immediate attention. (Hoffman

& Barstow, 2007, p. 9)

Many have emphasized the importance of understanding in the geosciences (Barstow &

Geary, 2002; Corgan 2008; Lewis 2008; Lewis 2010). The following cases emphasize why a

geoscience literate population is important. Bralower, Feiss, and Manduca (2008) predicted that

by 2050, the need for clean water for food and drinking will surpass supply, making it necessary

to develop new, affordable ways to clean water. Guha-Sapir, Vos, Below, and Ponserre (2011)

reported that in 2010, a "total of 385 natural disasters killed more than 297,000 people

worldwide, affected over 217.0 million others and caused US$ 123.9 billion of economic

damages" (p. 1). Recently, Hurricane Sandy ravaged the Eastern Seaboard to an estimated cost

of $30 billion to nearly $100 Billion USD (Geewax, 2012), with final death and injury counts yet

to be tallied. Iben Browning predicted a major earthquake event happening along the New

Madrid fault within 24 hours of 3 December 1990 (Spence, Herrmann, Johnston & Reagor,

1993), causing a news frenzy and people spending 22 million dollars to add earthquake insurance

to their homes. Many people did not heed that Browning had no background in geology or that

seismologists at the time had dismissed his claim. The earthquake never happened. Hall (2011) reported that Italian seismologists were being tried for manslaughter for NOT predicting an earthquake that took the lives of about 300 Italian citizens. A firm understanding in geoscience and science, in general, would go a long way to help people to understand the limits of science, determine the reliability of scientific claims, and to help to direct policy and mitigate loss of life and property.

In addition to the issue of geoscience literacy, Gonzales and Keene (2009) projected a sharp growth (19%) in geoscience related career opportunities, from 2006-2016, reflecting the increased interest in understanding how earth systems work and for the purposes of mitigating such effects of natural disasters on both people and property as noted above. This outstrips the average growth rate of all other companies in the country (9%). Growth in annual salaries is accompanying the growth in jobs. For instance Gonzales (2010) showed that from 1999 – 2008 average salaries for petroleum engineers increased by 27%, atmospheric and space scientists by 19%, geographers by 17%, and other geoscientists by 13%.

Despite the growth in job opportunities and salaries, there has been little influx of new geoscientists into the field. This has created an aging geoscience workforce, in that over 50% of current geoscience professionals are within 10 to 15 years of retirement age (Gonzales, 2008; Gonzales & Keane, 2010). Couple this trend with the trend in geology degree completion rates, currently running at about 13%, in comparison to almost 60% for other STEM Bachelor's degrees (Gonzales & Keane, 2008), and a great need of geoscientists appears eminent. The problem of producing geoscience graduates from college arises from many factors, such as low emphasis placed on geosciences in the K-12 setting (King, 2008; Lewis & Baker, 2010), low

emphasis in college (Gonzales, 2009), and also the way in which geoscience is taught in both of these settings (Seymour & Hewitt, 1993).

Teaching and learning in the geosciences for K – 16 students has been the topic of concern since the 1990s (Barstow & Geary, 2002). Lewis and Baker (2010) reported that currently, only about 7% of US high school seniors have taken an earth science course. There are approximately 10,000 earth science teachers at the secondary level in the US – much less than the 52,000 secondary level Biology teachers. It is this lack in exposure to earth science in the pre-college years that partially accounts for the low number of geoscience majors declared in colleges or universities (Gonzales & Keane, 2010).

Another issue regulating the number of majors is the waning emphasis on geoscience in post-secondary institutions. At colleges and universities across the country, the average size of a geology department, in terms of faculty, staff and instructors, as well as the number of majors declared, has steadily declined by about half from 1994 – 2007 (Gonzales, 2009). Gonzales asserted that a discipline's ability to attract the highest quality of students is dependent on members of the discipline to attract across gender and ethnic boundaries. As of 2007, geology students were overwhelmingly white males, with females, Hispanics, African-Americans, and Native students as compared to US population percentages.

A recent survey showed that almost 70% of geoscience majors decided to become majors either because they had an interest in geoscience prior to enrolling in college or university, or as a result of their introductory geoscience class they take as a freshman or sophomore (Wilson, 2012). This places great emphasis on developing interest in geoscience through enhanced teaching K – 16. As discussed previously, K – 12 US education provides very little geoscience education opportunity. Many undergraduates either do not enter a STEM discipline or exit a

STEM major due to teaching that emphasizes straight lecture and memorization of vocabulary and mathematical formulae (Fairweather, 2008; Seymour & Hewitt, 1997). Enhancing geoscience education, especially in secondary and post secondary education, looks to be a promising way to recruit and retain a new population of geoscience professionals.

Getting Post Secondary Instructors to Take up Innovative Teaching Practices

[A]lthough additional research may to useful to fine tune applications in specific STEM instructional settings and sub-disciplines, much research on effective teaching and learning already exists. The key to improving STEM undergraduate education lies in getting the majority of STEM faculty members to use more effective pedagogical techniques than is now the norm in the these disciplines. (Fairweather, 2008, p. 13)

As the need for STEM professionals was increasing, the supply of well-qualified employees was dwindling. Tobias (1990) and Seymour and Hewitt (1997) brought attention to the fact that many students, especially females and other underrepresented groups, were either not going into STEM disciplines on entering college, or if they did, left STEM prior to graduating. Seymour and Hewitt found that one of the core reasons for this flight from STEM was perceptions students had about science and math being "hard" because it involved memorizing vast amounts of vocabulary and facts. This perception came about as a result of the traditional, lecture-style format of teaching employed by most collegiate instructors. In response to this news, many colleges and universities created "centers for teaching and learning," and instituted professional development programs for faculty. The National Science Foundation (NSF) created programs focused on enhancing undergraduate learning through funding programs like the Course Curriculum and Laboratory Improvement Program (CCLI) and the current

Transforming Undergraduate Education in Science (TUES) program (Fairweather, 2008). As a result, much research has been done on the types of teaching that best facilitates student learning.

In his report, Fairweather (2008) stated that there is abundant evidence to show that more student-centered teaching practices increase student learning outcomes. Seeing these data is necessary for post-secondary instructors to assume some of these strategies in their own practice, but it is not sufficient to get them to invest the energy to alter that practice. For one, the culture of post-secondary education, including workloads, resources, and rewards, does not favor such an expenditure of energy devoted to improving instruction (Wright et al, 2004).

Research into how to increase secondary and post-secondary teacher efficacy has yielded many effective teaching tools including problem-based learning (Hodges, 2005), case studies (Herreid, 2007), collaborative discussions (Stein, Engle, Smith, & Hughes, 2009), argumentation (Kuhn, 2010), and the addition of technological tools (Sandoval, 2004). Despite lengthy descriptions of the development process and rationale for these and other interventions, there has been some published work looking at exactly how secondary instructors, charged with implementing such innovative tools, actually go about implementing it. There has been very little written describing this situation in a post-secondary context.

A useful model may be to consider the instructor a chemical reagent; meaning that (s)he reacts with only certain chemicals in a solution (tools in an intervention) and not others. That reaction produces new, or changed, substances (new or changed tools) that were not originally intended, but may still be useful. It is this kind of instructor-instruction interaction that Brown (2009) referred to when describing instructional development as a design activity. The instructor's personal framework ($PC_{xt}K$ of Barnett and Hodson (2001)), and the nature of the instructional tools (chemical structures of reagent and reactants, respectively), influence what

tools (s)he chooses to utilize (react with) and how (s)he uses them (the product of the reaction). The design of the tools needs to be familiar enough to the instructor that (s)he recognizes them as being useful. The design also needs to be flexible enough to accommodate different approaches to implementation and modifications, yet still be effective for teaching. For instance, a teacher may implement an activity (s)he learned at a professional development activity the day before, or (s)he may change the lesson plan in real time from multiple small groups to full class discussion when half the class does not show up due to involvement in a school assembly. As a result, the instructor's $PC_{xt}K$ is very influential in determining the efficacy of an intervention (Hulleman & Cordray, 2009), and implementing reform teaching becomes an issue of design (Brown, 2009), instead of an attempt to produce "teacher proof" tools. This dissertation focuses on this very important aspect of curricular design; how Eric's personal framework guided his decision making.

There has been a lot of interest in learning why teachers teach the way they do. One incentive is that this understanding could lead to influencing teachers to utilize more effective teaching practices. One very prevalent line of inquiry has been into teachers' beliefs about such concepts as teaching, learning, their students and the nature of knowledge (epistemology), how these beliefs relate to each other, and how they in turn might relate to the teachers' practice. Jones and Carter (2007) described the historical progression of determining teacher beliefs (subset of the personal framework of Barnett and Hodson (2001)). Researchers have developed and utilized many different instruments and surveys, interviews, as well as classroom observations to achieve this goal. It has also been the goal of science education research to link the espoused beliefs of teachers to their teaching practice. Once this connection has been made, it seems relatively straight forward to modify teacher practice to more reform based methodologies.

However, discerning the relationship has proved elusive. Oftentimes when teachers express what they believe about concepts like teaching, learning and science, their descriptions do not align with their classroom practices (Hodson, 1993; Lederman, 1999).

Addressing the Design Issue

Eric volunteered to implement an innovative curricular intervention in an iterative fashion, in two subsequent introductory geology classes, within the context of a multi-tiered teaching experiment (Lesh & Kelly, 2000). The focus of the investigation was to be on both student learning and instructor experiences implementing an innovative curriculum. The intervention was innovative because it utilized the science content in a historical context (using historical readings, biographies, data and models), and placed it into the structure of instruction purposely to emphasize and allow students to demonstrate their personal model building. However, Eric's implementation of the intervention was very much different from what was intended. It ended up being very teacher directed with mostly lecture as the vehicle of communication. This investigation attempts a novel method for accessing the influential factors of Eric's personal framework in an attempt to understand his decision making during the implementation period. The method of analysis is novel because it builds a story to explain Eric's decision making based on his use of metaphor when describing his experiences with teaching, learning, his students, and scientific knowledge.

The content domain of the intervention included earth dynamics pertaining to phenomena currently explained by the theory of plate tectonics. I grounded the structure of the intervention (a series of historical cases studies) within the best practices for teaching science as derived from cognitive science, and model-based learning literature, current geoscience conceptions research, and the nature of science research. In general, the intervention called for a student-centered

approach with emphasis on student model building, testing and amending, engaging in discussion, argumentation, and metacognition.

Eric utilized some of the intervention's teaching tools, but modified them beyond my expectations. He maintained a predominantly teacher-centered, lecture style classroom practice with some teacher-led discussion. Because of this change in the intervention, it became important to understand why Eric implemented the intervention the way he did. As a result, he became the focus of the study. Throughout the intervention, Eric and I maintained regular planning and debriefing meetings. I audio recorded these meetings as well as his classroom teaching for data. Upon review of the recordings, I discerned several themes that represent factors influencing or motivating his decisions during instruction. During a second iteration of analysis, I found that Eric often spoke with rich metaphorical language, and it is this language I utilize as data to build an explanation for why Eric chose, modified, or left alone certain tools of the intervention.

In other words, during the course of the implementation, the focus of the investigation changed and narrowed (Bogden and Biklen, 2007). Emphasis shifted to Eric and the decisions he made, concerning the tools he implemented and how, why he implemented them the way he did, and the language he used to describe his decision making. The resulting investigation takes the form similar to that of a qualitative case study (Bogdan & Biklen, 2007), while still part of a multi-tiered teaching experiment. It focused on Eric implementing a designed intervention and his personal framework and motivations to explain his instructional decisions. The analysis of the data answers these research questions:

1. What metaphors did Eric use when discussing concepts such as teaching, learning, and science?

2. In terms of the metaphors Eric utilized, how does he understand his role as instructor, the roles of his students, and the role of knowledge within the science classroom?

3. How do these understandings relate to Eric's teaching practice when implementing an innovative curriculum?

The answers to such questions will enhance the understanding of the factors influencing teachers' instructional decision making, a neglected area in the science education literature. This understanding will inform teacher educators about how to develop innovative curricular tools that are, at the same time, useful to teachers and effective for students; about preservice and in-service teacher professional development that meets the teachers where they are and facilitates growth in a direction of greater effectiveness; and about new ways to think about learning, beyond the "mind as container" (Bereiter, 2002) metaphor, so commonly used in today's educational forum.

CHAPTER 2: REVIEW OF THE LITERATURE

The goal of this chapter is to ground the multiple aspects of this investigation within its relevant knowledge base. These aspects include: the status of research in geology conceptual development, developing students' useful nature of science (NOS) understandings, designing the intervention curriculum from a model-based learning framework and utilizing the history and philosophy of science, factors influencing the implementation fidelity of such innovative curricula, and research into teacher beliefs as a prime factor influencing implementation fidelity. The chapter ends with an overview of the theoretical framework for data analysis.

The Status of Geoscience Education Research

This section organizes the relevant literature on students' geoscience conceptions into two categories: conceptions anchored in personal experiences and conceptions involving visual-spatial thinking. These are not mutually exclusive categories, but distinguished here for clarity. This body of literature grounds the design of this study's intervention.

Conceptions Anchored in Personal Experiences

Since the early 1980s, education researchers have been working with the understanding that students do not come to class as "empty vessels" waiting to be filled. Instead, they come to class with their own conceptions of how the world works based on personal experience. These "common sense" or "partial" conceptions seldom run parallel with current scientific understandings and are very resistant to change. These alternate conceptions will influence how a person understands the processes involved in shaping the earth. The most effective way to mitigate such conceptions is to know what they are and address them directly (Posner, Strike, Hewson & Gertzog, 1982; Strike and Posner, 1992). This section discusses some of the literature concerning student common sense (also referred to as alternative, naïve, or mis-) conceptions

relevant to geoscience. I subdivided students' alternative conceptions in geoscience, often anchored in personal experiences, into three subgroups similar to Cheek (2010): (1) the use of common definitions for terms as opposed to "scientific" meanings, (2) a subgroup relating to spatial or temporal scales beyond everyday experiences, and (3) a subgroup where students projected common experiences of phenomena onto abstract phenomena or those phenomena that cannot be directly observed.

Use of common terminology. Students often use terminology in ways that are more consistent with common discourse than with scientific usage. This is a contributing factor inhibiting meaningful understanding of science understanding (Cheek, 2010). For example, terms such as *rock*, *mineral*, *dirt*, and *soil*, which have specific meanings in science, are more or less interchangeable in everyday language (Cheek, 2010). She also noted how *flow*, with its common meaning akin to a river's flow, impeded the understanding of the plastic flow of the mantle because students' reasoned the mantle was liquid like water. Other researchers have documented terminology misuse regarding the different layers of the earth (Clark, Libarkin, Kortz, & Jordon, 2011) and *Pangaea* (Libarkin &Anderson, 2005). In sum, students' use of "everyday" vocabulary often negatively influenced their developing understanding of geologic concepts. Therefore, when designing the intervention for this study, great care was taken to engineer activities that fostered straightforward experiences, and opportunities for students to make their thinking visible during instruction, through drawing, writing, and discussion. Making thinking visible allows the instructor to be aware of that thinking and facilitates how the instructor might help guide that thinking in productive directions. Using straightforward experiences enhances the possibility that students' interpretations are better aligned and shared with others in the class.

Issues with scale. Students' also have alternative conceptions incommensurate with current scientific understanding regarding temporal and spatial scale (Blake, 2005; Cheek, 2010; Orion & Ault, 2007). This is relevant to geologic phenomena because processes are very slow, happen over vast areas, and involve forces with magnitudes beyond our everyday experience. For example, our common, daily observational capacity precludes us from observing the forces and speeds involved in continental movement, experiencing time scales near the order of geologic time, identifying large scale environmental patterns and the physical changes they represent, and understanding the existence, scale, and layering of bedrock (Blake, 2005). Students' cross-sectional drawings of the earth regularly exaggerated the thickness of the crust compared to the other layers. Students also thought earthquakes were the cause of folding in sedimentary rock layers (Cheek, 2010).

Projecting common experiences onto geologic phenomena. Students project their everyday experiences onto geological concepts addressed in class (Clark & Libarkin, 2011; Marques & Thompson, 1997). For example, they commonly think (a) continents and ocean basins have been relatively fixed through time, (b) continents are highest in the middle and oceans are their deepest in the middle (being pushed down under the weight of the water), (c) plate boundaries are at continental edges, (d) mountains are caused by vertical forces within the earth, (e) Earth has continued to cool since its origin, and (f) the rotation of the earth or tidal currents cause the plates to move. In other studies of students' thinking, students anthropomorphized the causes of mountain building and earthquakes and thought volcanoes only happened in tropical areas where it is warm enough to have them (Cheek, 2010). Students also think the continents are "floating" on a liquid mantle, melting happens at subduction zones as a result of compression, friction and increased heat, and convergence happens any place where

topography goes up (Clark & Libarkin, 2011). Sibley (2005) reported that students portrayed mountains as inverted cones on top of the crust with no roots, or as concave up warps in the crust, with no crustal thickening or mountain roots. Most concerning, however, was that when researchers presented these erroneous models to upper level undergraduates and beginning graduate students, the graduate students did not pick them out as erroneous. Perhaps this is understandable, as many of these conceptions are reminiscent of historical geologic conjectures (Oreskes, 1999; Şengör, 2003). Understanding students' alternative conceptions is important. If students think that volcanoes happen in tropical areas, this structures their understanding of the cause of volcanoes as being external to the earth, namely the sun, or somehow inherent to the earth's warm surface, rather than dynamics of the earth's interior.

The Role of Visual/Spatial Skills in Conceptual Understanding

Earth science learning relies upon visual-spatial thinking (Kastens & Ishikawa, 2006). Students need to utilize visual-spatial skills to interpret bedrock maps, stratigraphic cross-sections, and computer derived visual models. Despite this, there has been very little assessment of student conceptions utilizing drawings and other visual-spatial techniques (Sibley, 2005). When students draw their models, they have "1. Problems with setting up a correct static model of the layers, 2. Difficulties understanding causal and dynamic information…and 3. Difficulties with the integration of several different types knowledge including causal and dynamic knowledge into a causal chain to build an integrated mental model of systems" (Gobert, 2005, p. 448). Gobert also noted when students' drew representations based on reading, they achieved higher scores on written assessments, as opposed to those who only read without drawing afterwards.

The findings above align with research in cognitive science. For a novice to generate knowledge about a novel concept or deeper realizations of previous ideas, that new knowledge is built in an iterative fashion from the learner's prior understandings (Nersessian, 2008) and is often due to applying concrete experiences to more abstract ones (Lakoff and Johnson, 1999). Like "bootstrapping" in computer science, a learner utilizes pieces of knowledge from different and possibly unrelated domains and puts them together (Carey, 2008) by way of analogy, modeling, visualization (Gilbert, 2008) or thought experimentation. This occurs through an iterative process of building, evaluating and amending the model (Clement, 2008; Nersessian, 2008). Since geoscience conceptions are derived from the students' everyday knowledge and experiences, instruction must either encourage students to draw on their most appropriate experiences or provide those experiences for the learner to draw upon (Clark & Libarkin, 2005). The intervention design emphasized these understandings about conceptual development.

The Status of Nature of Science (NoS) Education Research

Since Conant (1947) expressed the importance for students to understand the nature and process of science and designed his college level science courses to reflect that importance, emphasis on students' understandings of NoS has increased. He referred to this as presenting "science in the making" (p.14). Many authors have promoted the incorporation of the historical, social, economic, philosophical, and technological influences on the progress of science (Allchin, 2012; Lederman, 2007; Matthews, 1994; 2012). What constitutes NoS understanding has been shifting from knowing a list of tenets, to including more active involvement, argumentation, and reflection by students on the processes of discerning reliability of scientific claims.

The "Consensus View" of NoS

There have been a number of thorough reviews of the literature concerning students' NoS conceptions and teaching to enhance those conceptions (Abd-El-Khalick & Lederman, 2000; Deng et al., 2011; Ledderman, 1992, 2007). Lederman (2007) summarized a "consensus view" that incorporates ideas that scientific knowledge is tentative, empirically derived, theory laden, culturally and socially embedded, and comes about through imagination and creativity. Using questionnaires and surveys, science education researchers have looked for the declaration of these "tenets" as a sign of "sophisticated" views of the nature of science (VNoS). See Lederman's (2007) table 28.1 for the alphabet soup of NoS instruments used over time to investigate this construct.

Shifting Emphasis to a Broader Definition of NoS

Irzik and Nola (2011) expressed concern that the consensus model was restrictive, endorsing a "family resemblance" definition. They defined characteristics of science (activities, aims and values, methodologies, and products) that might be expressed differently or hold different emphases in different domains. Osborne and his colleagues (2003) reported a broader interpretation of "ideas about science" that they thought important to teach in schools. These ideas included scientific methods and critical testing, science and certainty, diversity of scientific thinking, hypothesis and prediction, historical development of scientific knowledge, creativity, science and questioning, analysis and interpretation of data, and cooperation and collaboration in the development of scientific knowledge. As with Irzik and Nola, Osborne, and his colleagues discussed the "ideas" as having varying meanings and applicability, depending on the scientific context being discussed.

Finding scientific inquiry to be inseparable from nature of science, Deng, et al. (2011)

expanded the understanding of NoS beyond a declarative list, to include "a series of epistemic

and social activities, such as collaboratively discussing models, giving arguments for/against

models, and writing about models" (p. 963). Accordingly, students need to demonstrate the

ability to utilize the proper information to argue for a particular scientific knowledge claim in an

appropriate way. They must show the ability to use data as evidence when being critical of that

knowledge.

Allchin (2011) laid out a rationale for moving toward a more universal understanding of

NoS "unified by a theme of reliability" (p. 524); what he referred to as "*Whole Science*." He

delineated dimensions of reliability in science which include observations and reasoning,

methods of investigation, history and creativity, human context, culture, social interactions

among scientists, cognitive processes, economics and funding, instrumentation, and

communication and transmission of knowledge. These dimensions can only be addressed when

students experience and reflect on "science in the making" (Conant, 1947, p. 13) as opposed to

being presented with "ready-made science" (Latour, 1987, p. 4). Allchin proposed measuring

students' knowledge of NoS by their ability to judge reliability of claims based on the relevant

dimensions noted above, and how those dimensions have shaped the interpretation of data.

Shifting from the "consensus view" to this more situated approach to NoS shifts research

questions from "how do we get students to think this way about science?" to "how do students'

experiences doing science inform their understanding of how science works?" The design of this

study's intervention emphasized student engagement in scientific process and contextualized

experiences for discerning reliability of historical scientific models.

The Design of the Intervention

The intervention designed for this investigation drew from current understandings of model-based learning and took the form of historical case studies. It contained tools (discussions, activities, and argumentation) to elicit active student participation in mental model construction. Although the intervention is not the focus of this dissertation research, a background and rationale for its structure will help situate the reader for comparing the intended implementation with observations made during the implementation.

Investigators from diverse disciplines, including philosophers (Frodeman, 1995; Glen, 1982, 2002, 2005), cognitive scientists (Carey, 2010; Nersessian, 2008), historians of science (Giere, 1988; Rudwick, 1985), science education researchers (Clement, 2008; Duschl, 1990) as well as scientists (Oliver, 2005), have described variations of the same model-based learning process to characterize the generation of scientific knowledge. A common denominator among these diverse fields is that knowledge generation happens iteratively and involves the use of models. The process includes developing an initial model or framework to give meaning to observations. The model is critiqued and refined to assure connection to observations. This new model is once again scrutinized against observations. Researchers have witnessed this same iterative process as ordinary people generated knowledge that was not novel to the rest of the world, but was new to them (Clement, 2009; Halloun, 2004, 2007; NRC, 2005; Nersessian, 2008). It is this process of generating, critiquing and rebuilding models that is the centerpiece of the intervention in this investigation.

The spiraling Process of Model-Based Knowledge Generation

Duschl (1990) referred to the process of knowledge creation as a "rational feedback loop" (p. 49), an iterative cycle or spiral, as a model is developed, tested, and amended. The first stage,

model development, happens through visualization, induction, or mapping onto analogues (Buckley & Boulter, 2000). Several investigators considered the use of analogies (using concrete experiences as a proxy for a more abstract concept) as one of the key processes in mental model formation (Else, Clement, & Rae-Ramirez, 2008; Nersessian, 2008).

Once the initial model has been developed, the second phase is reconciling the model with observations of the phenomenon. During this evaluation (Nersessian, 2008), the model is mapped onto and compared with the phenomenon. The next step in the process concerns the adaption (Nersessian, 2008), or modification (Núñez-Oviedo et al., 2008) of the model to align it with observations. With minor inconsistencies, facets of the model can be added, subtracted, or amended to bring them into alignment. The model undergoes repeated cycles of testing and refining. Learning is not a "one and done" proposition according to this model. The learner must expend a great deal of effort, through many communicative exchanges to learn effectively. This is very different from traditional teaching where just exposing students to new knowledge by way of lecture or slides, means they have gained that knowledge.

Engineering a Learning Environment in Light of Model-Based Reasoning Strategies

The intervention design employed research from both the NoS and geoscience conceptual development literatures wrapped around the framework of model-based learning. Activities drew from literature emphasizing the use of such tools as historical case studies (Allchin, 2007, http://www1.umn.edu/ships/initiate.htm), historical narratives (Clough et al., 2006-2009; Clough, 2011), and contemporary case studies (Allchin, 2011; Herreid, 2007; Wong, Hodson, Kwan & Yung, 2008), "what if" scenarios (Khan, 2008), and discrepant questioning (Rae-Ramirez & Núñez-Oviedo, 2008). Laboratory activities were built in to instruction in a manner similar to "integrated instructional units" (NRC, 2006). This means that lab activities were to take place

within the flow of other classroom instructional activities such as lecture and classroom discussions. Labs were to allow students to "do science," collaborate with each other, and then reflect on the process. These facets contrast greatly with the conventional mode of laboratory activities and their relationship to the lecture part of the course, especially in the undergraduate science environment (NRC, 2006). Labs are typically verification activities that occur at a different time from the scheduled lecture and are not closely aligned, if at all, with lecture content. The NRC (2006) stated that noticeable benefits arose in both NoS understandings and content mastery, with integrated, student-centered laboratory experiences as opposed to those isolated from the flow of the class.

The main emphasis of the intervention was to utilize these multiple tools to elicit such model-based reasoning strategies as model competition and model confirmation or disconfirmation (Núñez-Oviedo & Clement, 2008), and use of analogies (Else, Clement, & Rae-Remirez, 2008). The goal was to get students actively involved with their own learning, to consider the process of their learning, and to draw parallels between that and the process of scientific knowledge generation.

For students to develop enduring understandings, in both geoscience content and NOS, the learning must happen in an environment and with a curriculum that makes students responsible for the cognitive "heavy lifting." They begin their learning already having ideas (with varying levels of coherence to current scientific understandings) about the content, and teachers must engineer an environment that best utilizes these ideas, facilitates new pertinent experiences, and fosters an alignment of students' understandings with what scientists currently think.

Many innovative curricular tools get developed with these goals in mind. The developer tests such tools under controlled laboratory conditions. In the naturalistic setting of the classroom, it is much harder to control many variables. For instance, the instructor's views on teaching, learning and the nature of knowledge may differ from what the curriculum developers anticipated. This affects the extent to which the actual implementation matches what the curriculum designers intended, and how well the students take up that intervention; a construct identified as implementation fidelity (Hulleman & Cordray, 2009). The following section discusses major influences affecting implementation fidelity.

Factors Affecting Implementation of Innovative Curricula

Curricula need to meet students where they are conceptually in terms of discipline specific content as well as NoS understandings. Instructors need to engineer experiences that are common enough among students so they can use them, build on them, and argue about them among each other. Design of curricular interventions needs to be sufficiently open ended to allow students to experience "science in the making" and supportive of students generating ideas that are productive; meaning they have good explanatory power. As I show in the findings in Chapter 5, the tension between presenting "ready-made science" versus students experiencing "science in the making" is prevalent throughout the data.

Curricular implementation has a profound impact on student learning, but such interventions are seldom implemented as designed (Hulleman & Cordray, 2009). Brown (2009) considered teaching a "design activity" (p. 18), and stated that, "Teachers must perceive and interpret existing resources, evaluate the constraints of the classroom setting, balance tradeoffs, and devise strategies – all in the pursuit of their instructional goals" (p. 18). Such variables as teachers' knowledge and perceptions, classroom setting, institutional structures, and culture,

affect implementation fidelity to varying degrees. The following section examines these variables.

Teachers, Culture, and Fidelity

Researchers have assessed innovative curricula by either evaluating the intervention as implemented (implementation fidelity) compared to the intended implementation, or by scaffolding teacher practice to bring it closer in line with researcher intentions. In their study, Hulleman and Cordray (2009)[2] measured implementation fidelity and found that those exposed to the intervention as designed received the greatest benefit of the intervention. This measurement is based on implementation in a naturalistic setting of the classroom as compared to a controlled laboratory setting for implementation. Any modification of the design of the intervention by the teacher is reflected as a decrease in fidelity. What they found was those receiving the intervention in the naturalistic classroom setting showed much less benefit, but still more than those not receiving the intervention at all. According to their data, teacher actions had the most impact on student learning; therefore they suggested that efforts to enhance fidelity by the intervention designers would be best aimed at the teacher level as opposed to the student level.

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[2] I qualify much of the literature in this section as coming from the context of K-12 (though, mainly secondary) science education. This study was conducted in undergraduate classes of non-majors. Despite this difference in context, there are striking similarities between what secondary science teachers and Eric perceive as constraints and norms for teaching science. This will be brought out when comparing the findings of this research with those of Höttecke and Silva (2011), especially in terms of their "culture of teaching physics" and "skills, attitudes and beliefs about teaching physics." In addition, Clough (personal communication) is having college professors implement NoS instruction (in the form of historical short stories) into their undergraduate classes. He is observing factors affecting implementation such as various constraints (e.g. classroom management, time), teachers' intentions, goals, and perceptions of students, teachers' views of the NOS, pedagogy, and perceived teaching outcomes, teachers' NOS understanding, and NOS PCK, teachers' perceptions regarding the value of NOS for teaching, sense of personal responsibility to teach the NOS, and views about how people learn. All of these have been written about, some extensively, in the K-12 literature, but are only now beginning to be addressed in a higher education context. The institution may be different, but the constraints seem to be remarkably similar.

Based on teacher interviews, Höttecke and Silva (2010) described the varied factors affecting implementation of history and philosophy of science (HPS) rich curricular tools by 10 groups of teachers from seven European countries and Israel. Teachers implemented HPS rich curricular tools in school science classes (mainly physics) ranging from 5th to 12th grade. They reported the following barriers to faithful implementation.

1. A culture of teaching physics that differs from other cultures of teaching other school subjects

2. Skills, attitudes and beliefs of physics teachers about teaching physics and epistemology

3. Institutional framework of science teaching with special focus on curriculum development

4. A lack of adequate HPS content in textbooks (p. 295).

The "culture" of teaching physics referred to the norms, values, and socially-shared practices characteristic within physics teaching. This culture of teaching physics included teachers having and conveying the "truth" about nature to students, where content was fixed and non-negotiable. The teachers often were positive about using HPS to teach content, but viewed it to be a didactic tool; and something *in addition to* what they already had to teach and therefore subject to time constraints. Given the lecture-based structure of geology classes, especially in the undergraduate setting, it is not hard to imagine a similar culture of teaching geology.

The teachers displayed "a strong tendency…to control discussions and close them down. The role of the students was restricted to answering questions put by the teacher" (Höttecke & Silva, 2010, p. 301). Traditional classroom designs also emphasized teacher authority. Teachers may have utilized HPS for teaching about the context of science, but they were uncomfortable teaching science as a process. Textbooks, often the standard for curriculum guidance, contained

representations of HPS within the texts that were misleading or naïve, located in dismissible sidebars, or absent altogether.

Orion and Ault (2007) found teachers to be the "limiting factor" to student learning, especially if they were not implementing instructional interventions according to design. They listed several factors "preventing [teachers] from genuinely implementing reform" (p. 679). One factor was pedagogical or professional inertia. That is, despite prolonged professional development, teachers reported they were not confident that professional development afforded them the resources for teaching outside their comfort zone, and they maintained traditional teaching styles. This reflects Barnett and Hodson (2001) who asserted, "Knowledge that enables teachers to feel more comfortable in the classroom and to enhance their sense of self is likely to be embraced; knowledge that increases anxiety or makes teachers feel inadequate will almost certainly be resisted or rejected" (p. 432-432). Similar to Höttecke and Silva (2010), Orion and Ault highlighted institutional constraints affecting implementation, like lack of resources (computer labs, equipment, smaller laboratory class sizes and access to outdoor learning) and the perception of time constraints. Realizing that teachers hold much influence on how curricular tools get implemented, researchers have tried to better develop teachers to enhance implementation fidelity.

Addressing the Teacher Factor

Emphasis on teacher growth. Mansour (2009) asserted that contextual constraints affecting teacher decision making had all but disappeared from teacher education research. Likewise, Barnett and Hodson (2001) asserted that teaching has been considered merely a technical execution of curricula;

No account is taken of the individual teacher's previous experience, personal

theories, and values; no acknowledgement is made of the uniqueness of each

educational environment. There is no recognition that teaching is a complex and

uncertain enterprise in which teachers are required to "think on their feet" and to

constantly adjust their approach in order to ensure satisfactory learning progress

for their students. (p. 428)

They continued that teachers should have control of their professional development, "thereby

freeing themselves from the powerful socializing forces of the profession and its governing

institutions" (p. 430). They spoke of socializing forces, or *microworlds,* that cause different

pressures on teachers' experience. First there is the microworld of science education, second is

teacher professionalism, third, the science curriculum, and finally, the school culture. Each

microworld has its own knowledge base (pedagogical content knowledge, classroom knowledge,

academic and research knowledge, and professional knowledge) and influences teacher behavior.

As described by Barnett and Hodson, pedagogical content knowledge includes understanding the

best way to present a topic, along with appropriate structure and allocation of time. Classroom

knowledge reflects the situational knowledge of the classroom and students. This is the

knowledge gained by the day-to-day experiences and decisions within the school and class

cultures. Academic and research knowledge incorporates the content and nature of science, the

history and philosophy of science, and the why and how students learn. Finally, professional

knowledge is the knowledge of being a teacher, passed on from experienced to novice

practitioner. It is the "teacher lore" or what teachers do as a matter of practicality.

Navigation through these four microworlds helps build what Barnett and Hodson (2001)

referred to as *pedagogical context knowledge* ($PC_{xt}K$). They posited that teacher development

(from novice to expert) happens as teachers become aware of these four types of knowledge and can utilize them based on the context or setting. Barnett and Hodson said that teachers need to understand their pedagogical context knowledge for them to become more effective. The advantage of the multi-tiered teaching experiment methodology of this investigation is that it exposes facets of these four types of knowledge for the instructor. I use this model as an organizing framework for the data in this investigation (Chapter 4).

In contrast to Barnett and Hodson (2001), who tried to understand the teacher's context and how it influenced her/his practice, Stein and her colleagues (Stein, Engle, Smith, & Hughes, 2009) tried to enhance teacher effectiveness with a more hands-on approach. Although they dealt with math teachers, issues with reform based math teaching run parallel with current reforms in science education. Stein et al. suggested that, in addition to implementing cognitively challenging instructional tasks that solicit multiple correct answers, novice teachers needed specific skills, "anticipating, monitoring, selecting, and making connections between student responses" (p. 314), to effectively facilitate whole class discussions. Teachers had trouble addressing unexpected turns in the discussion. The five skills are built on a framework that allows students to be authors of their own answers, yet still be accountable to the discipline. Stein et al. suggested focusing on the five different skills as a way to foster whole class discussion and give novice teachers experiences they might draw on in the future.

Teaching: A design activity. Brown (2009) viewed an intervention as an artifact to support the process of teaching; shifting the focus "from simply transmitting instructional ideas to transforming practice by serving as a catalyst for local customization" (p.18). Brown considered teaching a design activity. Teachers utilize tools based on perception, contextual constraints imposed by the classroom setting, and instructional goals.

An intervention is composed of tools, or strategies for teaching. These tools mediate teacher actions through the affordances or constraints they impose. In other words, the nature of the tool will favor (afford) certain actions and at the same time inhibit (constrain) other actions. Brown's (2009) main point was that teacher and tools modify each other in an iterative sense. Brown characterized the tools this way:

1. They are static representations of abstract concepts and dynamic activities – a means for transmitting and producing activity, not the activity itself.

2. They are intended to convey rich ideas and dynamic practices, yet they do so through succinct shorthand that relies heavily on interpretation.

3. They observe a number of culturally shared notational rules, norms, and conventions in their representations – although fewer consistently used conventions exist for curriculum materials than for sheet music.

4. They may reflect common or existing practices and at the same time aim to shape innovative or new practices.

5. They represent an interface between the knowledge, goals, and values of the author and the user.

6. They require craft in their use; they are inert objects that come alive only through interpretation and use by a practitioner. (p. 22)

Brown (2009) also discussed five different teacher influences on the tools. The first influence is the *selection* process. The teacher decides the day to day utilization of particular tools of a curriculum. Second, the teacher must make meaning of the tool, based on its design and her/his past experience through *interpretation*. Third, *reconciliation*, takes place when the perceived goals of the tool match with the teacher's goals for using the tool. The fourth influence

is *accommodation*. This is when the teacher uses the tool within the specific context of the class; timing, resources, and student abilities. *Modification* is the fifth influence and accounts for the teacher adding, subtracting, or otherwise changing the tool. The decisions determine the use of the curricular tools; whether they are *offloaded*, or used as is, *adapted*, or changed, or *improvised*, having no real correspondence to the original design.

According to Brown (2009),

The teacher–tool relationship involves bi-directional influences: how curriculum artifacts, through their affordances and constraints, influence teachers, and how teachers, through their perceptions and decisions, mobilize curriculum artifacts. (p. 23)

Understanding how a teacher would take up and utilize the different tools of an intervention is important and would come from knowing the "nature of teachers' goals and beliefs" (Brown, 2009, p. 28). This present investigation seeks to discern the relationship between how Eric implemented an instructional intervention and his goals and beliefs represented by what he said about teaching, learning, his students and the science he was teaching. Because there was significant difference between the intended implementation and what Eric actually did, understanding the relationship among the instructional tools, Eric's goals and beliefs and his decisions could help determine ways to bring the implementation closer in line with its intent.

In sum, low implementation fidelity was due to the teacher's skills and knowledge (Ault & Orion, 2007; Hulleman & Cordray, 2009; Stein et al. 2009), and perception of constraints and culture (Höttecke & Silva, 2010). Barnett and Hodson (2001) and Brown (2010) showed that there was an interaction among the teaching environment, the teacher, and the curricular tools. The main factor in the literature cited above is that teachers' beliefs played a major role in how

an intervention was implemented. Investigation into understanding this factor has a sizable body of literature. The next section addresses a portion of that literature as it relates to the present investigation.

Research into Teacher Beliefs and Teacher Practice

How Have Science Educators Defined and Studied "Beliefs"?

In order to study someone's beliefs, we need a clear working definition of "beliefs" and a way to make beliefs observable. Jones and Carter (2007) gave an extensive list of the variety of definitions of the concept utilized in the science education literature. There are also cases where researchers described "beliefs," but did not explicitly define it within the article (Brickhouse, 1990; Chai, Teo, & Lee, 2009). In his review of teachers' beliefs and practices literature, Mansour (2009) also acknowledged difficulty of defining this construct within the research literature. This is a major limitation for beliefs research. The following section is mainly concerned with how researchers measure teachers' beliefs about such things as teaching, learning and science.

Despite the limitations in defining the construct clearly within the science education litereature, researchers have approached discerning teacher beliefs and epistemologies from a number of different directions. Many have employed the use of open and closed ended questionnaires (Aikenhead & Ryan, 1992; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) and survey instruments (Chai et al., 2009; Eick & Stewart 2010; Kinchin, Hatzipanagos, and Turner, 2009). Others have developed interview protocols (Luft & Roehrig, 2007; Richardson & Simmons, 1994). Some less common strategies have included *Draw a Scientist* analyses (Minogue, 2010), the use of written metaphors (Both BouJaude; 2000; Reeder, Utley, and Cassel,

2009), and *critical incidents* – scenarios that have a teacher make decisions and take actions spontaneously, to help illuminate his or her belief systems (Kang & Wallace, 2005).

Of particular import to these studies was to measure different belief systems, especially as it pertained to teachers' beliefs about teaching, learning, and science. One goal was to use these measurements as a way to determine the efficacy of teacher preparation or professional development interventions. Researchers have also looked to teachers' espoused beliefs about teaching, learning and science to find how they might relate to each other. Discerning patterns in the results of such studies has been a challenge.

It is intuitive to consider how someone thinks about their own learning as consistent with how they think others learn, and that this would relate to their understanding of the nature of knowledge (epistemology). For example, if a teacher described his/her own learning as an acquisition of knowledge that is separate from him/herself, they might also see the learning of their students as a direct transfer of knowledge from teacher to those students, and scientific understandings being things that have been uncovered (or discovered), separate and distinct from the knower. Coherence among beliefs, such as this, has been referred to as "nested beliefs" and has been reported in teachers (Bryan, 2003; Tsai, 2002) and school students (Christodoulou et al 2010; Tsai, 2006).

The above cases are exceptions to what most researchers have found. Most often, reports have shown a multiplicity, or separation of beliefs. For instance, Kinchin et al. (2009) noted that in his study of graduate teaching assistants (GTA), who were teaching and conducting research in science were "paradoxically, shepherded toward the language of *objectivism* whilst endevouring to *construct* their personal understanding of their research problem" (p. 51, emphasis original). In trying to understand the belief system of her participant, Bryan (2003)

found that her participant maintained two sets of conflicting "nests" of beliefs. One nest seemed to influence her teaching, making it more traditional and teacher-directed. The other nest guided her vision constructivist teaching practices. Hodson (1993) could not categorize most of his participants along a coherent philosophical stance because the answers to interview questions "revealed substantial areas of confusion and uncertainty" with concepts such as the role of experimentation within scientific investigations. Both Hodson (1993) and Kang and Wallace (2005) also observed teachers maintaining dual perceptions of science. There was an "ideal" science, done by scientists, and the science that is done in a classroom under the perceived temporal, structural and social constraints.

The importance of pointing out these results is to show the difficulty many in the education literature have had in defining and/or measuring this construct of beliefs. Some found consistencies among sets of beliefs. Others found that beliefs about teaching were inconsistent with, say, beliefs about learning. At times, a person's beliefs about the same thing seemed to change depending on context. As discussed above, many of the instruments used to measure the beliefs construct (surveys and interview protocols) ask participants explicitly to describe their beliefs about teaching, learning and knowledge. Some have argued that when people are asked such questions, they make something up that is reasonable and then believe it (Kahneman, 2011). If, then, teachers are making classroom decisions "in real time" without the guidance of premeditation, the validity of descriptions of influences on those decisions (i.e. beliefs) should be questioned. This research attempts a different approach for understanding what Eric believes about teaching and learning and the nature of scientific knowledge by taking a more indirect route; analyzing his use of metaphor.

Beliefs Related to Practice

Educational researchers have tried to delineate the relationship between a teacher's beliefs or forms of knowledge and her/his teaching practice. The dominant teacher preparation model is that beliefs dictate practice, as expressed by the following passages: "Science teachers' epistemologies – which include beliefs about science, beliefs about teaching science, and beliefs about learning science – affect the type of instructional behaviors that occur in science classrooms" (Jones & Carter, 2007, p. 1075). "[W]e wonder whether individual beliefs about the nature and justification of historical knowledge influence history teachers' pedagogical choices" (Maggioni et al, 2009, p. 188). "It seems self-evident that teachers' own views about the nature of science and scientific inquiry will influence substantial aspects of their professional practice, including decisions about the design of learning experiences" (Hodson, 1993, p. 41). "[T]he constructivist-oriented SEVs [scientific epistemological views] appeared to foster the creation of more constructivist-oriented science learning environments" (Tsai, 2006, p. 222). According to this model, teacher educators need only equip teachers with reform-based knowledge and they will teach accordingly. "The next issue educators face is how to change teachers' 'traditional' beliefs about teaching, learning and science" (Tsai, 2002, p. 780). The results found in the literature, however, suggest that the relationship between teacher beliefs and teacher practice is much more complicated.

There have been a few investigations that reported findings in line with the model that teacher epistemological stance governed teacher practice. For instance, Brickhouse (1990) found that the epistemological stances she discerned from her participants reflected what she observed in their teaching. In addition, Tsai (2006) found that his participants who he identified with objectivist epistemological views (things have an inherent meaning independent of the human

mind) relied on a lecture format for their teaching, while the participants he identified having constructivist epistemological views (individuals create the meaning of objects in their mind) allowed student to explore in inquiry-based activities and also maintained more student-based discussion in class.

There are many more studies, however, that demonstrate a more complicated relationship. Hodson (1993) reported the few participants who maintained parallel philosophic stances among teaching, learning and science, maintained a stance that did not match their observed traditional teaching practices. He asserted, as did Lederman (1999) that the teachers made decisions in response to changes in content or their perceived ability of the class, and not their epistemology. Kang and Wallace (2005) found two teachers maintained more sophisticated epistemologies than their traditional teaching practice implied. They also cited context and other social influences affecting teacher decision-making. Both Jackson (2011) and Tsai (2002) identified a few teachers who had practices parallel to their epistemological stance. Where this happened was strictly with objectivist beliefs paralleling traditional practices. Both Jackson and Tsai reported that each of their sets of participants who espoused more sophisticated (constructivist) understandings of teaching, learning, and science, still maintained traditional, transfer teaching practices. To rationalize the discrepancy observed in her teacher participants, Jackson suggested "teacher context," especially time, beliefs about student ability, and classroom management issues affected teacher decision-making.

The findings illustrated in this section highlight the many different ways researchers have used to approach the problem of discerning teachers' beliefs and then connecting them to teachers' practices. Results have been conflicting; there is a question of nested beliefs versus a multiplicity of beliefs, and beliefs coherent with practice versus beliefs inconsistent with practice.

Mansour (2009) acknowledged contextual circumstances to be at least partially responsible for the observed dissonance between teachers' espoused beliefs and their practice.

> The similarities and differences in teachers' beliefs might be a product of the different degree of the interaction between the contextual levels and the influence of that interaction on the teachers. What happened in the classroom can be determined to a degree by school policy, which in turn is affected by the educational system. (p. 33)

The root of the discrepancies noted above may be a result of the nature of the instruments being used to understand teacher beliefs. In most cases, questions ask the participants explicitly about their beliefs concerning teaching, learning and science or to explain their practice. The limitations of this approach become obvious in the following section. The section builds an argument that most of our decisions are made unconsciously, structured by unconscious metaphorical understandings of the environment and explanations of such decisions are often created *post hoc* and accepted as causal beliefs. It builds an argument for a framework of data analysis that more accurately portrays understandings and explains and predicts practice.

Theoretical Framework – Metaphors: Understanding One Thing in Terms of Something Else

Reddy (1979) asserted that the English language "has a preferred framework for conceptualizing communication, and can bias thought processes toward this framework" (p. 285). He was referring to the *conduit metaphor*[3] of communication. According to this metaphor, ideas are likened to *objects* that we can *give* to others. The transfer of ideas from speaker/author to audience happens by way of *containers* or the words we *put our thoughts into*. Finally,

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[3] Throughout this dissertation, and especially here and in Chapter 4, italicized words and phrases are meant to bring the reader's attention to the identification of a metaphor, as in *the field trip metaphor*, or metaphorical language such as *push them to make a conceptual leap*. This is a strategy to further make visible the data analysis.

communication is considered the *conduit* that the speaker/author uses to *get* his/her meaning *across* to the audience. Reddy spoke of great social and political implications of this metaphorical framework. Many authors have subsequently added to and expanded this original work (Grady, 1998, Kahneman, 2011; Lakoff & Johnson, 1980, 1999). I describe these works below to make an argument for using metaphor as the lens through which to analyze the data collected during this investigation.

The Conduit Metaphor (Reddy, 1979)

In an attempt to explain certain problems in communication, Reddy (1979) identified the *conduit metaphor*. He claimed that the semantic structures of the English language lead its speakers into a particular frame that can create barriers to real communication. According to the *conduit metaphor*, thoughts or ideas are things that can be given and received.

1) She tried to *get* her *thoughts across* to the audience, but they were *not receptive to* her *ideas*.[4]

In addition to this aspect, words are containers that can hold the ideas or thoughts.

2) It took a lot of organizing, but he was finally able to *put* his *thoughts into words*.

Finally, Reddy pointed out that language, or communication, was perceived as a conduit for transferring the ideas from the originator of the thought or idea to someone else.

3) It took a lot of persuasion, but I think I finally *got through to* him.

To demonstrate his point about communications, Reddy developed an analogy. The analogy was in the form of a story (the tool maker's paradigm) about a large wagon wheel shaped compound with spokes dividing up six sections within the compound. Though each pie-shaped section (walled on two sides by "spokes" and the third by an arc of the circumference) had a similar

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[4] The numbered sentences within the theoretical framework section are examples of the use of metaphors in our everyday language. *Italicized* words highlight the metaphorical language within each sentence for clarity. Unless otherwise noted, the numbered sentences are the product of the researcher.

environment to the others – water, trees, small plants, soil, etc. – none of the environments were identical (Figure 1). Each person needed to survive in their section of the compound on his or her own, and was not directly aware of anyone else in the compound as there was no way to communicate directly with anyone else. They were only indirectly aware of the other through the use of a communication device located at the "hub" of the compound. Through this device, a person could share information about tools or food or other survival techniques by producing crude plans or blue prints to be placed within the communication "hub." The device distributed the plans to others in the compound. In this analogy, Reddy pointed out that the people living in
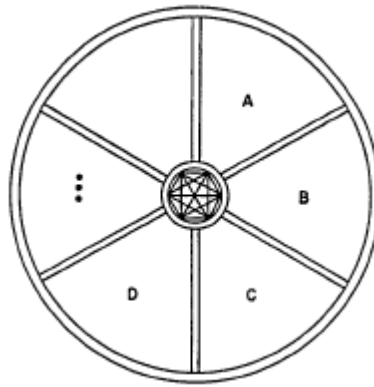
Figure 1. Diagram of the compound in Reddy's tool makers paradigm. From Reddy (1979, p. 293).

the compound are like us, in that we have no direct way to share our ideas. The only way sharing does take place is through the use of signs and symbols, paralleling the writings placed into the communication device. The person's environmental resources, what each used to survive, represent our personal repertoire; "the internal thoughts, feelings, and perceptions which cannot themselves be sent to anyone by any means that we know of" (p. 293).

Reddy developed a scenario where a person (A) developed a tool, a rake, which he found very useful, because his environment was heavily wooded. He created a crude set of prints on its construction to send to the others via the communication device. Person B received the

instructions and proceeded to fashion the tool for himself. Reddy explained the troubles person B encountered.

> Sector B, on the other hand, runs more to rock, and person B uses a lot of rock in his constructions. He finds a piece of wood for the handle, but begins to make the head of the rake out of stone. *A*'s original rake head was wood. But since it never occurred to him that anything but wood would be available or appropriate, he did not try to specify wood for the head in his instructions. When *B* is about half way finished with the stone rake head, he connects it experimentally to the handle and realizes with a jolt that this thing, whatever it is, is certainly going to be heavy and unwieldy. He ponders its possible uses for a time and then decides it must be a tool for digging up small rocks when you clear a field for planting. He marvels at how large and strong person *A* must be, and also what small rock *A* must have to deal with. *B* then decides that two large prongs will make the rake both lighter and better suited to unearthing large rocks. (p. 293-294)

Having finished his construction, *B* drew some plans and sent them to the others in the compound. *A* received the plans, found them intriguing, but saw that *B* must have misinterpreted his original instructions and so began to fashion new instructions to help clarify. The communication continued back and forth with *A* eventually becoming frustrated that he could not clearly communicate his ideas. Eventually, as Reddy described, *A* had an insight where he developed iconic representations for "rock" and "wood" and this clarified much in the sets of instructions involved in the exchange to the satisfaction of both *A* and *B*.

Reddy contrasted the tool makers paradigm with a similar story that would be analogous to the *conduit metaphor*. In this story, the communication device at the hub would be more like a

duplicating machine. Person *A* would place his rake within the hub, push a button and replicas of the rake along with knowledge of its use get sent to the others. In this scenario, everyone is aware of everyone else's environments. Most importantly, communication is successful with no investment of effort. Any form of miscommunication would be an aberration whereas in the tool makers paradigm, "partial miscommunication, or divergence of readings from a single text, are not aberrations. They are tendencies inherent in the system which can only be counteracted by continuous effort and by large amounts of verbal interaction" (p. 295).

Reddy (1979) asked whether utilizing the *conduit metaphor* while communicating could affect the thought patterns of those within the communication. To demonstrate the implications of the *conduit metaphor* on thinking, he extended the tool makers story by having an evil magician hypnotize the dwellers of the compound

> so that, after they received a set of instructions and struggled to build something
>
> on the bases of them, they would immediately forget about this. Instead, he
>
> planted in them the false memory that the object had been sent to them directly
>
> from the other person, via a marvelous mechanism in the hub…They still had to
>
> build the objects themselves, out of their own materials – but the magician
>
> blinded them from this. (p. 307)

In this way, the mode of communication via symbols and signals on a piece of paper needing to be deciphered stayed the same, but because the residents no longer appreciated the effort involved in communicating with one another, the communication device rapidly fell into disuse. Since the individuals forgot that they bore a great deal of responsibility for the shape of the tool they made from the directions given, it became easy to blame the sender for any defects in the tool. There was no feeling of having accomplished anything, because once they had finished

their very hard work of deciphering the signs and signals and spent labor building the tool, they forgot about all of that energy they had invested. Instead, they attributed all of the creativity to the person who sent it to them. They eventually became lazy and did not want to participate in any activity that would require them to invest any work or creativity.

In Reddy's view, communication within the frame of the *conduit metaphor* disregards all the energy used by the receiver of communication to both decode the message and then construct meaning for it, and the credit for creativity goes to the one sending the message. The *conduit metaphor* implies success in communication comes with little or no energy expenditure, and any failure in communications is the fault of the receiver of the communication. In an educational context, the conduit metaphor does a good job explaining why direct instruction through lecture is the predominant practice. If teachers think that the meaning of their words is sent to students with those words, then engaging students in such model-based learning activities as drawing, discussions, negotiations of meaning, or metacognitive activities are not necessary. As long as students hear the words (or read them) and they are receptive, the onus is on them to "get it." This idea runs parallel to the *mind is a container metaphor* and *acquisition metaphor of learning* that Bereiter (2002) and Sfard (1998), respectively, critique as insufficient for explaining how learning actually happens.

Metaphors We Live By (Lakoff & Johnson, 1980)

Lakoff and Johnson (1980) incorporated Reddy's discussion of the *conduit metaphor* into a larger framework of metaphor use and its effects on our perceptions of reality. They developed the argument that beyond the artistic and poetic use of metaphor, understanding abstract concepts is rooted in our daily perceptions and experiences with our five senses. The understandings result from the embodied nature of our sensory input enabling us to understand the abstract in terms of

concrete, embodied experiences. In other words, we utilize experiences gained through our bodily senses (embodied experiences) and apply them to abstract concepts, where we do not have direct experiences, to make meaning of them. Learning about or understanding one concept in terms of another, is also reflected in the writings of Carey (2010) and Nersessian (2009). Of major import, Lakoff and Johnson described "experientialism" as an alternative to the universality of understanding associated with "objectivism" and the individuality of understanding associated with "radical subjectivism." With experientialism, our experiences are embodied and personal, the result of our physical interaction as an individual with the environment. Due to our common biology and environment, we do share those experiences on a general level. They also discussed that the metaphors we live by create experiential gestalts, the backdrop influencing how we interpret all other signals from the environment. That gestalt, or backdrop, highlights certain aspects about the signals being understood and hides other aspects.

Metaphors are pervasive in our everyday language and influence how we understand the concepts highlighted by those metaphors. For instance, Lakoff and Johnson (1980) gave an example of *argument is war metaphor*.

4) He could not *defend* his claim of innocence.

5) The *defense* attorney followed a very *aggressive line* of questioning.

6) She *poked holes into the very foundation* of his argument.

7) In the end the *rivals* could not *come to terms* and *make peace*.

Statements 4 – 7 demonstrate only a few examples of how we can understand the concept of argument through our understanding of the concept of war. Lakoff and Johnson went on to say that

Since metaphorical expressions in our language are tied to metaphorical concepts

in a systematic way, we can use metaphorical linguistic expressions to study the

nature of metaphorical concepts and to gain an understanding of the metaphorical

nature of our activities. (p. 7)

Lakoff and Johnson further developed the *conduit metaphor* (Reddy, 1979) and the systematic

ties between language and concepts. They asserted that sentences such as

8) The poem she wrote *captured* perfectly the feelings of loss we had all experienced.

9) His statement *was full* of vitriol and hatred.

10) It took a lot of arguing, but he *finally got his ideas through to* the building planning board.

demonstrate how ingrained this particular metaphor is in our understanding of communication.

These sentences do not appear to be metaphorical, and in fact convey quite typical meaning.

The *conduit metaphor* is an example of a structural metaphor; the target concept –

communication – is mapped onto the structure of the source concept – things, containers, and

conduits. Structural metaphors are grounded in experience. Take for instance the following

expressions for understanding or knowing something:

11) I *see* what you mean, but did you consider this?

12) I *hear* what you are saying and I agree with you one hundred percent.

13) The detective was hot on the *scent* of the killer.

14) Now that I have done some of the homework, I have a *taste* for how to perform these

mathematical operations.

15) It only took looking at a map to get a *grasp* of where I was.

Because we come to know things mainly through the use of our senses (embodied cognition), we

couch our understanding of "coming to know" something in terms of those senses. Lakoff and

Johnson pointed out that this idea seems to favor radical subjectivism, where there are no universal truths and every person's reality is based on individual experiences. Indeed, Reddy (1979) made this claim. However, due to our common biology and environment, we share, on a general level, these experiences with other humans to the point that the metaphors are useful devices to help others understand what we are saying. Lakoff and Johnson described *experientialism*[5] as the alternative to the absolute and universal meaning reflected by objectivism and the solely personal meaning reflected by radical subjectivity.

Lakoff and Johnson (1980) discussed the idea of experiential gestalts, or how interpreting one experience metaphorically sets the stage for interpreting other related experiences within different aspects of the same metaphor. If we understand an argument in terms of the *argument is war metaphor*, then we form a coherent understanding of all the parts of the argument in terms of the different aspects of a war. Participants are adversaries; the difference in opinions is the conflict. Planning the argument requires strategizing and garnering evidence or marshalling forces. There are attacks, and counter attacks. Each person defends his/her position. In the end they agree to disagree (a truce), one person changes his/her position (surrender), or neither is convinced by the other's argument (stalemate). This is called *mapping* entailments of the metaphor.

This coherent structuring, however, is only partial. There are only certain aspects, or entailments, of the source concept (war) that get mapped onto the target concept (argument); highlighting certain aspects of the target concept, while at the same time hiding others. Concepts also get structured by multiple different metaphors. For instance, the concept, "Love," is very

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[5] An example of the difference of experientialism from objectivism and radical subjectivism is the meaning we give to the concept, "dog." We each have a general enough idea (a family resemblance), based on a multitude of experiences with multiple different dogs, that we can recognize a dog when we see one, regardless of breed, and we can talk meaningfully to others about dogs. However, because meaning is based on personal experiences, no one maintains the exact meaning of "dog" as anyone else.

abstract and almost exclusively thought of in terms of different metaphorical structures or gestalts; *e.g.* Love is a journey, a patient, a physical force, madness, war, etc. (Lakoff & Johnson, 1980, p. 85). "Structuring" creates meaning for the abstract concept by using the concrete experiences of the source domain of the metaphor. In the *conduit metaphor*, objects or things are the concrete concepts. They give meaning, or structure ideas or feelings, to the abstract concepts. For the conduit metaphor, containers are the concrete, structuring words, the abstract. Conduits are concrete, while language is abstract. Accordingly, we can put our thoughts into words and give a piece of our mind to someone else.

> Lakoff and Johnson (1980) claimed:
>
> In all aspects of life, not just in politics or in love, we define our reality in terms
> of metaphors and then proceed to act on the basis of the metaphors. *We draw*
> *inferences, set goals, make commitments, and execute plans, all on the basis of*
> *how we in part structure our experience, consciously and unconsciously, by*
> *means of metaphor.* (p. 158, emphasis added)

We use the experiences from one domain to create understanding or to structure our understandings within a second domain. These understandings become our beliefs, are mainly unconscious, and they help determine our actions.

The Conduit Metaphor Revisited (Grady, 1998)

In an attempt to clarify some inconsistencies in Reddy's (1979) and Lakoff and Johnson's (1980) analysis of the *conduit metaphor*, Grady (1998) reexamined its metaphorical structuring and evidence for such structure in the English language. Because comprehending structural metaphors has the precondition of an experiential basis from which to draw its meaning, he searched for and was unsuccessful finding a relevant basis for the *conduit metaphor*. Grady

therefore proposed the *conduit metaphor* to be a compound metaphor that he deconstructed into more general primary metaphors, including *constituents are contents*, *achieving a purpose is acquiring a desired object*, *information is contents*, and *transmission of energy is transfer*.

Grady (1998) pointed out that statements like sentence 2) "It took a lot of organizing, but he was finally able to *put* his *thoughts into words*," are a predominant idea in the *conduit metaphor*, where some constituent (thoughts) is contained within some other structure (words). However, there are other sentences following this same pattern that are not related to communication.

16) There are 60 seconds *in* one minute.

17) She could barely *contain* her excitement.

18) He had a nutritious breakfast, *full* of vitamins and minerals.

Grady identified this general structure as the *constituents are contents metaphor*. According to the structure of this metaphor, objects (a nutritious breakfast) contain their characteristics as constituents (full of vitamins). This comes from our experiences observing objects that may be differentiated into smaller parts by color or shape or use. We perceive the smaller parts to be contained within the boundary of the whole object. He also observed that when we add ingredients to something, these ingredients move toward and then into the space taken up by the object. In this way, though the object is not a formal container, the ingredients are perceived within the boundary of the object.

A second primary metaphor, the *achieving a purpose is acquiring a desired object metaphor*, addresses another group of structures. This metaphor structures the whole as a container for holding or giving up independent entities. A *conduit metaphor* example looks like the following example.

19) The class reading was so *dense* that I could not *get any information out of it*.

As pointed out earlier, there are also metaphors within this structure that do not pertain to communication. For instance,

20) I studied so hard and felt that the test was *in the bag*.

21) She continues to *reap* the benefits of somebody else's hard work.

22) I could tell by his questions he was *fishing for information* about the case.

In each case, a particular goal (passing a test, acquiring benefits, gaining information) is perceived as an object and the act of acquiring that object is taking it from a kind of container acting as "a barrier between us and the object we desire" (Grady, 1998, p. 11).

In all, Grady demonstrated that the *conduit metaphor* is actually a compound of four different primary metaphors: *constituents are contents metaphor*, *achieving a purpose is acquiring a desired object metaphor*, *transmission of energy is transfer metaphor* and *becoming accessible is emerging metaphor*[6]. By doing this he bridged the gaps in data that were visible when mapping from a single metaphor as opposed to the "collection of structures" illuminated above. He also provided more examples of how our physical experiences shape our conceptual understandings and the language we use as a result. These points become particularly salient in Chapter 4 for understanding the two compound metaphors Eric used during the study.

Philosophy in the Flesh (Lakoff & Johnson, 1999)

Philosophy in the Flesh (Lakoff & Johnson, 1999) expanded on many of the points brought up in the previous works.

- Reason is not completely conscious, but mostly unconscious.

- Reason is not purely literal, but largely metaphorical and imaginative.

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[6] I have bypassed Grady's (1998) explanations mapping the other two primary metaphors, *becoming accessible is emerging*, and *transmission of energy is transfer*, as there was nothing new to be gained from such description. I encourage those interested in following Grady's argument to follow up in his original work.

- Reason is not dispassionate, but emotionally engaged.

- Reason, or conceptual systems, is not universal but shaped by commonalities among our bodies, brains and environments that we inhabit, allowing for common stable truths. (p. 11-12)

Basically, Lakoff and Johnson (1998) put forth that according to Western philosophical tradition, humans have the ability to reason independently from the mind and body, with no connection of reasoning to the mind, nor connection of mind to the brain and body. They critique this as being wrong. Our physiology structures how reasoning happens. To make this point, Lakoff and Johnson discussed our perception of color. Color, they said, is only perceived by us through a combination of four factors; two external to us (wavelength of light and lighting conditions), and two embodied (rods and cones in the eye and neural pathways linking the eyes to the brain). "Colors do not exist in the external world. Given the world, our bodies and brains have evolved to create color" (p. 20). Color is an internal representation of the reflectance properties of the studied object. It is not a substance separate from human body and mind, but inherent to it.

Following this line of thinking, spatial relations concepts do not exist in the external world. Concepts such as nearness and farness, in front of and behind, and across, do not exist, but are our impositions on the external world; done automatically and unconsciously by our conceptual and perceptual systems. For instance, we impose "front" to the part of an object that we normally interact with or to the part of an object pointing in the same direction that it normally moves. Lakoff and Johnson (1998) explained this development of metaphor as the integrated theory of primary metaphors. Primary metaphors are the least structured and most

encompassing metaphors and can be combined (conceptual blending) to produce more and more complex metaphors. Based on this theory,

> We acquire a large system of primary metaphors automatically and unconsciously simply by functioning in the most ordinary of ways in the everyday world from our earliest years. We have no choice in this. Because of the way neural connections are formed during the period of conflation, we all naturally think using hundreds of primary metaphors. (p. 30)

The "period of conflation" refers to a time early in a child's life where (s)he conflates subjective experiences and judgments with objective sensorimotor experiences that happen concurrently. This conflation explains how an infant's sensorimotor experience of being held close eventually gets conflated with the subjective experience of affection and is then responsible for concepts like a *close* friend and a *warm* smile. The neural connections made between the sensorimotor experience and the subjective experience during the period of conflation allows us to use a repertoire of related words for the sensorimotor experience to give meaning to the subjective experience.

We can put pieces of this repertoire of primary metaphors (all grounded in concrete experiences from our youth) together in different ways to develop compound metaphors. Lakoff and Johnson (1990) discussed the compound *love is a journey metaphor* as an example. Assembling the primary metaphors, *purposes are destinations*, *people with a purpose are travelers*, *actions are motions*, *intimacy is closeness*, and *a relationship is an enclosure*, they show that having a loving (purposeful) relationship, two lovers (travelers) are together (closely enclosed, like in a vehicle). They built the compound, *love is a purposeful journey metaphor*, and used expressions related to a journey to give meaning to the relationship. For instance:

23) They've only just met, but their relationship seemed to be *on the fast track*.

24) Their relationship *hit some bumps in the road* but they managed to *get through them*.

25) He wanted the marriage to last but realized they were just *spinning their wheels*.

The *fast track*, *bumps in the road*, and *spinning wheels* are metaphorical idioms derived from the *journey* portion of the *love is a purposeful journey metaphor*. They produce cognitive images. According to Lakoff and Johnson (1999, p. 40), the presence and usage of such idioms

- Demonstrate that words can designate portions of conventional mental images

- The conventional images are shared across people speaking the same language

- The conventional images are a significant part of our cultural knowledge

- The idioms are not just a figure of speech but invoke conventional images which are then subject to further metaphorical mapping; they extend the original metaphor and enrich its meaning.

Lakoff and Johnson (1999) stressed that we do not just talk about love in terms of a journey, magnetism, electricity, heat, madness, illness, magic, etc., but understand love in terms of these metaphors. The multiplicity of metaphors we use enriches its meaning of the target concept (love) and allows us to reason about it. This unconscious reasoning "governs conscious behavior as well as unconscious behavior" (p. 53). To demonstrate, they pointed out that the concept "neural computation" is merely a metaphor, but is so useful, it is considered embodied truth. This idea of the multiplicity of metaphors becomes relevant in Chapter 4 when describing the two metaphors Eric used to describe teaching, learning, and the status of scientific knowledge.

Thinking Fast and Slow (Kahneman, 2011)

The theme of the cognitive unconscious control over our perceptions and actions continues in Kahneman's (2011) book, *Thinking Fast and Slow*. To explain decision making in

humans, Kahneman presented the mind as two systems of thinking: system 1 and system 2. System 1 thinking as fast thinking, takes little or no effort, is unconscious and automatic, and responsible for such tasks as depth perception, showing and detecting emotion, identifying the location of a sound, performing various routines, answering 2+2=?, and recognizing and interpreting stereotypes and metaphors. System 2 is slow thinking. It does the conscious reasoning, making choices, focusing attention, searching the memory for a name, and monitoring and maintaining proper behavior within social situations. Kahneman said we think we utilize system 2 thinking the most, but it is actually the unconscious and automatic impulses from system 1 thinking that handles the vast majority of our day-to-day activities.

System 1 thinking develops a quick answer to a question, emerging as an intuition that seems reasonable. We act on it without critical analysis. Critical analysis is often skipped due to a process of association during this quick and unconscious thinking. "Ideas that have been evoked trigger many other ideas in a spreading cascade of activity in your brain. The essential feature of this complex set of mental events is its coherence. Each element is connected, and each strengthens the others" (Kahneman, 2011, p. 51). Even if the stimulus for the reaction is an association of words with a particular concept, the mind reacts to those words as if it were experiencing the actual concept the words were representing.

This associative mechanism Kahneman described parallels the experiential gestalt of Lakoff and Johnson (1999). Kahneman called the triggering of this associative mechanism in the brain, *priming*. For instance, he reported that participants in an experiment who recently had experienced the word, *eat*, completed the spelling of SO_P as SOUP much more often than as SOAP, and that the opposite resulted when they had been exposed to the word, *wash*. Each time, the word, *eat* or *wash*, primed how participants viewed the rest of the world, or created

associations within a particular context that they then acted on. "Primed ideas have the ability to prime other ideas…Like ripples on a pond, activation spreads through a small part of the vast network of associated ideas" (Kahneman, 2011, p. 53). Priming also affects actions. "If you were primed to think of old age, you would tend to act old [moving slower, for instance], and acting old would reinforce [reciprocal priming] the thought of old age" (p. 54). Symbols and metaphors play a large role in these associations.

It is Kahneman's (2011) idea of priming that is pertinent to this to this investigation. As Chapter 4 shows, Eric utilized two compound metaphors when talking about teaching, learning and science. I argue that his use of the language structured his decision making by priming and/or reinforcing his ideas of his role, his students' role and the role of knowledge within the classroom setting.

Understanding the Hidden Framework for Decision Making

Understanding how the brain works, what our beliefs are, and what influences the decisions we make is a difficult task. We are limited to observing the effects of the workings of the brain and inferring a mechanism for those observations. In education research, understanding the beliefs of teachers and how they relate to their practice has been a goal for decades (Jones & Carter, 2007). I described above, how assessing teacher beliefs normally took the form of surveys and interviews, where the teacher participant answered questions specifically aimed to elicit their beliefs. The instruments were administered and interpreted under the assumption that beliefs are the result of premeditated and rational thinking; what Kahneman (2011) would identify as System 2 thinking. However, based on the previous review on communication and the importance of metaphor, most of our thinking is not premeditated and rational. In fact, we are unaware of most of the thinking our minds do. It happens automatically and unconsciously. As

Kahneman so aptly put it, "If asked for an explanation, however, you will search your memory for presentable reasons and will certainly find some. Moreover, you will believe the story you make up" (p.415).

From the evidence and arguments presented by Reddy (1979), Lakoff and Johnson (1980, 1999), Grady, (1998), and Kahneman (2011), access to the thinking that controls most of our decisions seems to be through the metaphors we live by. Kahneman identified system 1 thinking and Lakoff and Johnson, the *embodied cognitive unconscious*. Both contended that most of our daily decisions, judgments, and interpretations, and skills are performed by our brain but without our knowledge. This makes us susceptible to bias in terms of Kahneman's *priming* or Lakoff and Johnson's *experiential gestalt*; where one experience contextualizes the perception of the experiences that follow. On the one hand, this will highlight certain aspects of those experiences, but will hide aspects as well. Metaphor, understanding abstract concepts in terms of more concrete experiences, is a major mechanism in this priming or experiential gestalt.

We learn about our environment based on our interaction with it. A baby develops understandings about an object from the concrete experience of taking hold of it and putting it in her mouth. In later years she can *grasp* that abstract concept in math class, or *get a taste* for art from a weekend workshop. Because our interactions are personal, our experiences are personal. However, due to commonalities in our biology and environment, we are able to relate experiences meaningfully among ourselves, through the use of shared metaphor.

The mechanism of the experiential gestalt is the extended mapping of metaphors from the source to the target domain. For instance, we can look at a loving relationship as a journey (*purpose is a journey metaphor*) and this determines how we experience different aspects of the relationship. If the relationship is good and strong, the experience is *smooth sailing*. If there are

some troubles in the relationship (*troubles are impediments to motion metaphor*), say one of them *strayed* from the relationship or was just *going along for the ride*, the experience is that of *turbulence*, or *bumps in the road*, and at the worst, they are *spinning their wheels* or have *reached a dead end* in the relationship. We may, instead, consider the *love is a patient metaphor*. Here we can see a couple with a good relationship has a *strong* or *healthy* one. Over time the relationship may seem *listless*. This may result in a *sick* relationship. The couple could either decide to work together to *save* the relationship by *pumping some life into* it, in which case it would be *on the mend*, or it may be a *tough pill to swallow*, so they let it *die* with *no hope of revival*. The associations are automatic and unconscious and rely on the personal experiences with the source of the metaphors (being a traveler or a patient). This idea of mapping multiple metaphors shows up in the data gathered from Eric.

As discussed by Kahneman (2011), system 1 thinking understands these metaphors and its associations as real, not figures of speech. It can make inferences from and further extend the metaphor; making further associations. The mind is in the world of the journey or the patient and makes decisions based on experiences from that context, not based on the loving relationship. Love is a hopelessly abstract concept, but the mind does understand being on a journey, being impeded from motion, being sick and being healthy. Likewise, observing an instructor's teaching as well as the metaphors (s)he uses while discussing concepts about teaching, learning, students, and science, will give insight to that instructor's structured reality and help explain her/his instructional decisions; the decisions whose reasons are outside the realm of her/his conscious view. This is different than probing, explicitly for the instructor's beliefs, because based on the literature cited above, much of our actions are subject to the unconscious biases of the brain; causes that are invisible even to the owner of the beliefs. Observing how the instructor behaves

and how (s)he describes teaching, learning, and knowledge, structured by the context of her/his experiential gestalt that can inform the observer of the influencing mechanisms in the instructor's decision making.

Summary

This literature review has put forth a number of assertions and rationales within the context of this current investigation. There is a need to enhance learning in both the geosciences and with regard to the nature of science. To do this effectively, instruction must allow students to build their own models and test them, make their own arguments, and discern the reliability of the claims and arguments of others. They must experience "science in the making." Traditional, teacher directed, lecture-based teaching, presenting "ready-made science," does not accommodate these essentials.

Attempts at designing and importing curricula to address the issues noted above have shown very limited implementation fidelity, even with attached professional development. This means that creating tools for teaching cannot happen without regard to the context of the targeted user of the tools and the culture in which he or she teaches. Such "ready-made teaching" is not effective. Rather, teaching is a design, or iterative, activity; "teaching in the making." Attempts to understand teacher beliefs have shown limited reliability because teacher words (what they say when asked what they believe) often have not reflected or predicted teacher actions. Part of this is due to the nature of the instruments used, which ask for conscious descriptions or rationales for mostly unconscious beliefs or actions. This research is not studying how the participant instructor explained his teaching. Rather, it builds an explanation based on how the instructor described events of teaching, learning, and knowledge use by him and his students. It seeks to explain a geology instructor's decisions by analyzing the expressions of that decision

making in terms of the metaphors that structured Eric's teaching context. It seeks to answer these questions:

1. What metaphors did Eric use when discussing concepts such as teaching, learning, and science?

2. What does Eric's use of metaphor tell about the meaning he holds for such concepts as teaching, learning, and science?

3. How might these meanings be related to Eric's teaching practice when implementing an innovative curriculum?

CHAPTER 3: METHODS

In this chapter, I review how I gathered and analyzed the data to address the research questions. The review begins with the setting of the study, and follows with a brief review of design-based research techniques within the context of multi-tiered teaching experiments (Lesh & Kelly, 2000). This literature forms the foundation for the research approach I took in this study in terms of tools for teaching, the data and data gathering protocols, and the use of metaphor as an analytical tool. I end the section with a description of the data analysis process showing how I determined themes and how I identified Eric's systematic use of the metaphors.

Setting

Eric implemented the instructional intervention in two different undergraduate introductory geology courses taught in an R-1 institution in the Northeast United States. Each course was held during one of two successive summer sessions. The first course, mainly for non-majors, met two hours per day, four days per week, for six weeks. It had no lab. The second course, generally for geology majors, met five days per week with two of those days designated for laboratories. These were led by a graduate teaching assistant (GTA). Despite the difference in their intended audience, the scope of the content for each course was virtually identical. The first class had 25 students enrolled, the second, 13. All students participated in the class activities as they were the regular instructional strategies for the class. Students were asked to participate in the investigation through an e-mail request prior to the beginning of the class and brought an informed consent letter (sent with the e-mail) with them to the first class or signed an extra copy at the first class. Every student in each course agreed to participate and be audiotaped during the intervention period. The instructor, also a participant, had already graciously agreed to let me into his class and to participate fully in the investigation. I selected him as a participant because

he taught both courses and expressed interest and willingness to participate in the design and implementation of the instructional intervention. A much more contextual description of Eric exists in the next chapter.

I observed three classes prior to the first iteration of the intervention. In these classes, students sat at long tables, set in rows, all facing the front of the room designated by a white board and projection screen. Students came in and sat down, with little interaction. Each time, Eric started a PowerPoint presentation and lectured for approximately one hour, then took a ten minute break, and lectured again for the remainder of the class (another 30 to 40 minutes)

Design of this Study

In the early 1990's, educational researchers began implementing investigatory methodologies that have collectively become known as design-based research (Brown, 1992; Collins, 1992). This methodology utilized an engineered intervention typical of experimental investigations, but did so in the naturalistic classroom setting. Important to this methodology is the freedom to modify the intervention, in real time, with the goal of enhancing its effectiveness. The purpose of this type of investigation is to develop theory for teaching and learning that could then be used as a starting point for investigations in other venues. Hoadly (2004), O'Donnell (2004), and Sandoval (2004) have described important strengths of design-based research. Such strengths are that the classroom is a more authentic location to influence and observe student learning and instructor teaching. Designers can refine the instruction as needed. The collaboration allows opportunity to build a much stronger relationship between the researcher and the teacher (Lesh & Kelly, 2000). Also, at the end of the process, there is a tool, or series of tools (teaching strategies), that have been refined and are ready for use.

This methodology begins with the researcher designing instructional tools grounded in a model of learning. Next the researcher decides on the outcomes (s)he will focus on to determine the efficacy of the tools. The researcher then must identify the data necessary to evaluate the outcomes. At this point, the instructor enacts the intervention, looking for opportunity to make short-term changes needed during the class or for subsequent classes, and also long term changes for future iterations of the intervention. Finally, the researcher analyzes and compares the collected data with the original conjectures to check for alignment. In most cases, the researcher must realign (amend) the conjectures, the tools, or the model in response to the collected data. The researcher then implements the new and improved tools in a continuing iterative fashion. At times, due to its iterative nature, the focus of the study also changes.

Several examples of this iterative process exist in the research literature. Brown (1992) changed the location of the intervention and student tasks as she attempted to develop metacognitive reading skills in her students. Hoadly (2004) changed the focus of his investigation from student use of designed software to the variables involved in its implementation. Joseph (2004) shifted from a study of "communities of interest" to aspects of learning (student motivation and decision making). Kenyon, Davis, and Hug (2011) redirected from preservice teachers' scientific model building, to focus additionally on their using, evaluating, implementing and revising models. In all of these examples, researchers paid attention to the intervention, or the students, but not to the role the instructor played implementing the intervention and what effect (s)he had on the intervention's efficacy.

Note how design-based research methodology bears a resemblance to the iterative process to knowledge generation as those associated with model-based reasoning described in Chapter 2. The researcher develops a model and determines its implications, creates tools based

on the implications, tests the tools and evaluates them based on the gathered data, and amends

the model or the tools to align with observations. For this study, the focus is the instructor's

decisions for tool (lecture, discussion, historical case studies, texts, laboratory activities, etc.) use

and modification during the intervention.

Critique about design-based research includes the very large amounts of data collected to

make only modest claims grounded in the local context, questionable generalizability of

conclusions, risk of seeing only the data that fits the theory, and no structured methodology

(Dede, 2004; Kelly, 2004). However, others have argued the benefits outweigh those critiques

(Anderson & Shattuck, 2012). The benefits include a blending of intervention design within the

social context of the classroom, promoting reflection and critique by both the researcher and

instructor, helping build relationship between researcher and instructor (Gravemeijer & van

Eerde, 2009). Although conclusions might not be wholly generalizable, the product of design

based research is an enhanced, theoretically-based instructional tool that might be used

reflectively in other appropriate environments. Furthermore, the findings from this investigation

address the void in the literature concerning the instructor as an integral part of the design-based

experiment process; one crucial factor (filter) that lies between the designed intervention and

student learning outcomes.

I implemented a type of design-based research known as multi-tiered teaching

experiments (Lesh & Kelly, 2000) in this investigation. The goal of multi-tiered teaching

experiments, "is to go beyond studies of typical development in natural environments and to

focus on induced development within carefully controlled environments" (Lesh & Kelly, 2000,

p.197). The goal of the intervention was to engineer a learning environment where students could

form their own understandings of phenomena within boundaries that guide those understandings toward improved scientific thinking.

Multi-tiered teaching experiments utilize a hierarchy of research questions. In this study, I was interested in the student and instructor levels. The teacher level became the main focus of this investigation; I became interested in Eric's ideas about teaching, science, the textbook, the intervention, learning and the students, all as factors influencing his instruction.

As with any investigation, there are limitations that influence the results and their generalizability. In this investigation, because it is a single case of a teacher implementing an instructional intervention, the results could have limited generalizability, especially with regards to the metaphors used by Eric and how they structured his teaching. Other teachers may structure their teaching using different metaphors. A second limitation is that Eric implemented the intervention in two relatively small summer courses, not reflective of the typical size of most introductory science courses. Most introductory or service level courses have many more students in them (hundreds as opposed to tens), further exacerbating the difficulties for facilitating meaningful small group and whole class discussions as called for in the intervention. Also, the amount of time allotted for the summer courses was shorter than typical semester courses. This affected the implementation of the intervention's readings, especially, and may not have been as much of an issue if spread out in a typical 15-week semester. Lastly, due to the greater numbers of students in traditional semester courses, it is much more difficult to synchronize the laboratory experiences with the regular class work. During the investigation, laboratory activities could be implemented when most appropriate allowing for coherence. This is much more complicated with separate laboratory sections taking place at various times through the course of a week.

In the spirit of transparency, I also describe my subjectivity and position within this investigation to give more context concerning the intervention, the intended implementation, and the decisions I made that affected the research direction and outcome. I was formally educated as a geologist and worked within the capacity of a geologist in the environmental industry. Subsequent to that, I became certified to teach earth science and worked in a public school setting for approximately 13 years, teaching ninth-grade earth science. It was during this time that I became interested in the history and philosophy of science, and especially of geology, and began developing lessons within historical context. During my final five years of teaching I developed a unit of instruction that combined both the traditional units of "the dynamic earth" and "geologic time." The unit was a historical treatment to answer the question, "Why do we still have mountains?" This curriculum influenced some of the structure for the intervention developed for this study. Some of the activities in this study reflected what I did in my earth science classes. A main difference from this previous curriculum was the addition of the readings of historical scientific papers. I had the experience of the teaching in this manner. I did not have experience studying its efficacy in a systematic way.

My decision to leave the public school setting for a PhD program in science education came about based my desire to learn how students learn through the use of models and how utilizing historically contextualized cases and activities might facilitate that process. I began developing a curriculum that approached the same goals just described, teaching about the concept of plate tectonics, but from a different direction. Instead of asking, "Why are there still mountains?" I wanted to utilize personal accounts of the 1906 San Francisco earthquake and use seismology as a thread to tie the rest of the information together. I knew Eric prior to the investigation. We had had a couple of interactions, including some discussion about teaching and

learning. I found Eric to be very knowledgeable, engaging, and enthusiastic as an instructor, though I had not observed his teaching. When I talked about my proposed study, he offered his classes as a possible venue for conducting my research. I was excited at this possibility, because, and as I discuss later in the findings, we both seemed interested in the same goals for teaching. Eric said he was interested in engaging his students and having them put their ideas together. It seemed to me that we wanted the same thing.

Tools for Teaching

In this section, I describe some of the structure and philosophy behind the intervention. The design of the intervention came from a model-based learning framework. It is important to overview the framework and the intervention in order to evaluate how the tools of the intervention were adopted, modified, or rejected by Eric.

The model-based reasoning theoretical framework is the conjecture (Tabak, 2004) that under-girds this investigation. Students were to engage in iterative model building during the sequence of instruction. The instruction utilized historical cases and inquiry activities. The case studies described historical figures related to the development of the theory of plate tectonics and provided context for the geological data introduced. The activities in the intervention highlighted the chronology of geologists' historical and emergent understanding of the theory of plate tectonics. As students gained new data (either historical or derived from activities) or information, they could compare the data with their current models. This approach aligns with the "interrupted case study" approach (Herreid, 2007; see also Allchin, 2007; Leaf, 2011).

The case studies and inquiry activities demonstrated how geologists built and tested alternative models to explain earth dynamics (expanding, shrinking, drifting, and sinking). Thus, the history of scientific knowledge creation becomes a model for knowledge creation in students

(Clement, 2008; Nersessian, 2008). Flores-Camacho, Gallegos-Cazares, Garritz, & Garcia-Franco, (2007) even showed that students can hold multiple competing models for a single phenomenon at once. As it happens in science, individuals can change their model based on observations, or when they apply it to novel situations (Sclater, 2001). In addition, social context (political, economic, technological, etc.) oftentimes influences scientific models and the direction of investigations. The influence of the social context on science parallels the influence of an individual's sensitivities toward discerning patterns in nature. An individual's learning depends on the background of the person, her/his interests, their special abilities or limitations. Making these parallels evident to students helps them to understand their learning and the process of scientific knowledge generation.

This is not to say that the path to understanding for an individual would be parallel to the path science took. Serendipity in science precludes any such common path (Glen, 2002), though instruction can "engineer" a likely path, using history to set bounds for models the students can formulate. Students would see how various social factors (gender, skepticism of new disciplines like geomagnetism, WWII, professional rivalries, etc.) influenced the direction of understanding. If pressed, they could come to realize that they are also subject to influences on their understanding of the environment. The intervention for this study had students reflect on the role their biases play in their learning in order for them to take a more active role in their own learning (Flores-Camacho et al., 2007; Georghiades, 2000, 2004). An organizing principle of the intervention was having students constantly compare their evolving model with existing data to ensure it corresponds. For instance, students should be continuously asking, "what kind of model…?" What are the other implications of the model?" "What are the predictions I can make from the model?" "Do the predictions match available data?" "If not, how do we have to change

the model to answer to the data?" This type of reflective practice, when made explicit can help to illustrate the students' progression in learning as well as the process of scientific knowledge generation.

Data and Data Gathering

I used an Olympus WS-110 digital voice recorder and a Tascam DR-680 8-Track Portable Field Audio Recorder to record verbal interactions between Eric and me and Eric and his students. With the DR-680 unit, I recorded conversations happening at eight different microphone locations within the classroom. Any group or laboratory work occurred at these microphoned locations. I also observed and made field notes of each of the classes during the intervention period. I observed 15 full, two-hour classes of the intervention; 10 during the first iteration and five during the second iteration. I utilized an observation protocol developed for this investigation. The protocol maintained a marking system I utilized to identify behaviors or discourse associated with student actions (use of data, explanation, analogy, etc.), teacher actions (storytelling, explanation, demonstration, etc.), and general classroom activity (small group discussion, whole class discussion, lecture, etc.). There was also a section for general notes. For ease and clarity of recording these observations, the protocol (Appendix A-1) was divided into a grid with "student actions," "teacher actions," "classroom activities," and "notes" heading vertical columns and class time in five-minute increments dividing the columns into horizontal rows. I used a large digital clock in the class to facilitate the accurate records of action over time.

To study how Eric understood teaching, learning, his students, and discuss the intervention and its implementation, I met with him one month prior to the implementation and twice more the week before the initial implementation. I audio recorded these meetings and also recorded field notes. We met 15 times for varying lengths of time prior to and/or after almost

every (Eric's schedule permitting) class of the intervention. The meetings lasted for as little as four to five minutes to as long as 30-40 minutes. During these meetings we discussed the progression of the implementation, what Eric was planning on doing, or what he did, why he did it, and his understandings of how it went, what he might like to change for the second iteration, and what that change might look like. After the second post-class meeting, I also interviewed Eric formally about his background and previous experiences with science and teaching and to gain insight to his motivations for participating in this research project (See Appendix A-2 for interview protocols). This interview lasted about 40 minutes.

We had one meeting between the two courses. This meeting involved the GTA for the second course, as well. Approximately one hour long, it focused on planning for the intervention and synchronizing its implementation with the labs being planned by the GTA. We had a series of pre- and post-class meetings during the second iteration of the intervention. Approximately two weeks after the conclusion of the intervention, Eric and I met a final time for an interview about his thoughts and understanding of the intervention. I also asked him questions to clarify some of his previous comments. This meeting lasted over an hour.

I transcribed all audio recordings of conversations between Eric and me within a day of recording them. My analysis of the transcripts (see below) started as soon as I had transcripts to analyze. As I read through the transcripts I noticed a few comments that Eric made – feeling he *had* to use a text, uncomfortable silence, difficulty being an expert and teaching introductory classes – that he never came back to elaborate on his own. Because these comments seemed integral to Eric's understanding of teaching and learning, I wanted to get a deeper explanation for what he meant when saying them. I used these instances as the foundation of follow-up questions in the final interview to gain some clarity concerning his meaning.

Data Analysis

I designed this study as a query into how students learn and how the instructor experiences implementing HPS-rich curriculum emphasizing model-based learning. During the investigation, the focus changed and narrowed (Bogden & Biklen, 2007) to understand why Eric took up certain tools of the intervention while leaving others. If Eric was indeed a reagent between the design of the intervention and its implementation, I wanted to understand the nature of that reagent, (namely, how did Eric understand his role, his students' role and the role of knowledge in the classroom) what he changed in the process of reacting, and why (how his understandings influenced the instructional tools)?

Using a grounded theory approach (described in Bogden & Biklen, 2007) for my analysis, I transcribed the recordings and read the transcripts as I was collecting additional data. I began to notice excerpts that indicated Eric's understandings of teaching, learning, science, and the intervention that seemed significant and repetitive. These passages seemed to indicate factors and motivation for his instructional decisions. I developed a concept map that displayed these significant and repetitive comments. I put related passages into general groupings that I refer to as themes. The themes that I discerned were Eric's descriptions of students, of teaching and teaching science, teaching strategies, the text book and other readings, descriptions of science and the scientific method, Eric's expressions of scientific knowledge, and statements of negotiation and planning concerning implementation of the instructional intervention. Approximately 60 or 70 excerpts from the transcripts support each of these major themes.

There were eight patterns that cut across these original themes described above. Six of them indicated a particular context that influenced the choices Eric had when making his instructional decisions. I identify these as Eric's $PC_{xt}K$. These were his struggle between

structure and student self-direction for class work, understanding knowledge as being objectively real, teaching with the end in mind, the constraint of time, understandings of the textbook and understandings of students. Each of these patterns allowed only certain instructional options for Eric to choose from to do his teaching. The other two patterns, authority and responsibility, I identify as motivations. They provided incentive, or the reason, for Eric to make his instructional decisions while the first six give insight for the options he had for the particular decision he made.

As I parsed more excerpts into these categories, I noticed that Eric also maintained a use of certain language reminiscent of Reddy's (1979) *conduit metaphor*. He often referred to teaching as "*giving pieces* of information" to his students and that they would put the pieces together or "*shelve them* in their *library* full of facts." I looked closer to discern a pattern to Eric's use of this metaphor, and I also familiarized myself with some of the more common *primary metaphors* as described by Lakoff and Johnson (1999). With this new analytical lens, I began to notice a pattern of metaphors of motion within the data. Eric repeatedly talked about "taking students *though*" a particular topic, having students make "a leap…a conceptual leap." He would "pull them into" a topic or "keep them on track." I was able to categorize the vast majority of the passages containing metaphorical language into four groups, each represented by a primary metaphor. The four primary metaphors were *thinking is manipulating objects*, *thinking is moving*, *object event-structure (events are objects)*, and *location event-structure (events are locations) metaphors*. From these primary metaphors, I constructed compound metaphors; the *puzzle metaphor* (a compound of *thinking is manipulating objects* and the *object event-structure metaphors*) and the *fieldtrip metaphor* (a compound of the *thinking is moving* and *location event-structure metaphors*), based on his specific language. These compound metaphors were

consistent and formed the basis of two different macro-themes apparent through the entirety of the transcripts. For the *puzzle metaphor*, Eric referred to knowledge in terms of "bits and pieces of information" or "pieces of a puzzle" that he gave to students who then, through logic, assembled them into a "coherent picture." In terms of the *fieldtrip metaphor*, Eric described learning being a long journey; a journey that "started" at the beginning of the unit where he wanted students to "gear up" and "get ready to roll." He said things, like, "leading students through" the content, or giving them "a push" in hopes of having them "make the jump" and helping them to "get from A to Z." The following section demonstrates the process of analysis from raw data to $PC_{xt}K$ themes to mapping the metaphors for a selected passage from the data.

Tracking a Passage through the Analysis Process

To demonstrate the process outlined above, I take the following passage from the data through the different stages of analysis. The passage is Eric's reflection on some of the challenges he experienced implementing the intervention.

Umm, one thing else that was- one thing that was particularly difficult for me was the self-directed part. That- I had a hard time making that work very well. Umm and I think part of it is - part of it I think is, is because at the intro level it's sometimes difficult to have self direction work. It's too easy to let them flail. And with more time over a longer interval, I think letting them flail is very effective. Right? But, with such a short time and so few contact hours, uhh, the amount of wasted time flailing becomes a real issue. It stops being a learning tool, a motivational tool and starts being a real impediment. People just get frustrated and there isn't enough time to recover from that. (201200809:347-357)

In the first round of analysis, this quote fit into the theme, views of teaching science. The quote illustrates a lot about the contrasts between the self-direction in the activities of the intervention and Eric's understandings of teaching science in a more structured sense.

For the second round of analysis, this quote illustrates a couple of the patterns of Eric's $PC_{xt}K$ and motivation as described above. One pattern illustrated was the struggle between structure and student self-direction. Eric found it very hard to make student self-direction work well. The pattern of constraint of time was also part of the passage. For Eric, there was not enough time to have students "flailing." If it were a course of longer duration, this might not be a problem, but because of the context of a six-week course, Eric found it hard to rationalize using self-directed activities. Eric also expressed The pattern of resposibility to his students. He was responsible for getting them through the course on time, and he had a responsibility to keep them from being so frustrated that they ceased to learn anymore.

Once I had discerned the $PC_{xt}K$ themes, I went back through the data, highlighting Eric's use of metaphor throughout all of our conversations. I created a bubble map using Inspiration[®] concept mapping software to group passages by the primary metaphors in Eric's discourse. These primary metaphors were *mind is a body* and *event-structure metaphors*. Eric referenced two of four different sub groupings of the *mind is a body metaphor*, *thinking is manipulating objects*, and *thinking is moving*, most often. He also referenced portions of the *location event-structure* and *object event-structure metaphors*. I mapped approximately 90% of all passages with metaphors onto these four different metaphors. The other passages mapped onto metaphors such as *thinking is perceiving*, *thinking is eating*, and the *moving observer metaphors*. I also categorized all but five passages based on the general grounded theme of the passage, teaching, learning, students, science, the intervention, and textbook, and expressions of scientific

knowledge. These were general themes discerned from the first bubble map of themes described above. The five passages not categorized by a main theme were either descriptions of college classes (*massively accelerated*), or Eric's concerns of *grabbing* control or *letting* it *go.*

Below, I describe the *location event-structure metaphor* followed by a figure (Figure 2) giving a graphical representation of that description. The figure contains a central light blue rectangle identifying the primary metaphor. Radiating out from the central rectangle are light blue rectangles with rounded corners demonstrating the mapping of the entailments, or associations and extensions, of the primary metaphor. An arrow from each of these rectangles attaches to a final rectangle which gives an example of an excerpt from the data that was coded as that particular primary metaphor.

Location event-structure metaphor. This metaphor considers events or states as locations, usually inside bounded regions (Lakoff & Johnson, 1999). In this case, the event is learning something, and therefore considered a location somewhere in space. The act of learning is therefore journeying from some starting point to the location of having learned. An extension of this metaphor is the concept that any difficulties along the journey are impediments or barriers to motion.

Once I had categorized all of the passages, the two compound metaphors were obvious. The passage fits the category, intervention, because Eric's focus was on describing a particular aspect of the intervention; the self-directed activities. It also maps onto *fieldtrip metaphor*. The metaphorical phrases signify Eric as a leader of the field trip. He had trouble letting students direct themselves. He thought with *more time* and *longer interval* it might be better. Otherwise student frustrations and flailing would be *a real impediment* and they could not *recover from that*.

Figure 2. Example of coding for the *location event-structure metaphor*. Metaphor entailments are light blue rectangles with rounded corners and examples of text coded to that primary metaphor. The salmon colored boxes represent quotes about teaching; the green box, about science; the bright pink, about students; and the orange, about learning.

And leading them through that- and I think they got some pieces. I mean, he was, he was right on. He was like, "Hey, if it's not expanding, then doesn't that stuff that gets created in one place have to be destroyed?" Yes. Absolutely. Absolutely. That's right. You know and getting them to make that jump, you know, it's a conceptual jump. And then they can go back and start filling in some of the pieces. Because there's lots of little if-then statements that get you from A to Z. And yes, going from A to Z is correct. It's like Wegener. Right? He really did get it. But he didn't get all of the if-then statements that got him from that starting point to the finishing point.20120620:43

And then, and then, and that's the thing they start seeing; the contortion that people put themselves through defending their model. And that's when you know when things are on the down hill slide. 20120614b:189

Actions are self-propelled movements

vocabulary is such a barrier for people who might intuitively or, or, or maybe not intuitively but actually be intellectually get what is going on 20120611:b124

Long-term, purposeful activities are journeys

Location Event-Structure Metaphor - Events are locations (L&J, 1999, p. 88)

Difficulties are impediments to motion

to order or structure that allowed me the freedom to learn in my own way and my own pace within a structure that kept me on track to get me through the material. 20120611b:241

Changes are movements (into or out of bounded regions

States are locations (interiors of bounded regions)

Causation is forced movement (from one location to another)

It's also interesting flipping back and forth between lecture, discussion and play 20120611b:100

Umm. Or don't have the words, so there's that. Umm, part of it is, part of it is that getting to the point of being able to discuss that material requires, requires reading it. 20120614b:29

And see if I can pull them into hot spots, satellites, radio telescopes 20120713:13

Shifting Emphasis

This research began as an investigation of the experiences of introductory geology students and an instructor with curriculum designed to elicit student model building within the domains of earth science and the nature of science. The following chapter describes the intervention in detail. I utilized multi-tiered teaching experiment methodologies to accomplish two goals. I sought to record (through audio recordings and science notebook entries and classroom observations) instances of student model building to better understand the interplay between student and curriculum. I also recorded interactions with Eric to better understand his professional development as he implemented the curriculum.

What transpired through the duration of the investigation was an unanticipated change, by Eric, of the implementation of the intervention. The extent and significance of this is described in the next chapter. It was the magnitude of this change that caused me to modify my research focus to Eric's instructional decision making. The relevant issues became understanding Eric's location; his multiple forms of knowledge, motivations, and how he structured his teaching reality. The relevant data became what Eric said and did while teaching and while talking about teaching. Of particular importance were the metaphors Eric used when talking about teaching, learning, and science. Based on analysis of his use of metaphors (especially the *mind is a body* and *event-structure metaphors*) from the transcripts of our interactions, I describe two compound metaphors Eric used that explain the instructional decisions he made. These data are presented in Chapter 5.

CHAPTER 4 THE INTERVENTION AND IMPLEMENTATION

This chapter contains two parts. The first part outlines the structure of the intended intervention for helping students develop their mental models within the realm of earth dynamics as it pertains to the theory of plate tectonics and enhancing students' understandings of NoS. The second part recounts examples of Eric's implementation. Eric's alteration of the plan for implementation and the instructional tools were significant enough to warrant changing focus of this research to instructor decision-making.

The Plans

The intervention began by introducing students to earthquakes; a common, worldwide phenomenon with rich historic tie-ins to the understanding of how the earth works. Students were to read two eye-witness accounts of the 1906 San Francisco earthquake; one written by Jack London (London, 1906) and one written by William James (James, 1911). Students were to compare and contrast the two descriptions in a Venn diagram in their science notebooks. Students would record their initial mental model of earthquakes in response to the readings and the question, "What is an earthquake and what causes one?" Students would also observe video footage of earthquake devastation in various YouTube videos.

Students would then be asked to imagine that they were on a team to investigate the 1906 earthquake and devise a plan for trying to determine the cause of the earthquake. In this plan, they needed to specify where would they look and what would they look for to try to determine the cause of earthquakes. Students would then be presented with a biography of Harry Reid and his data (Reid, 1910), in the form of simplified diagrams. They needed to develop an explanation for the data. Class discussion would ensue as students tried to make sense of the data. Eric would ask such question as, "What was Reid's approach to collecting data?" "What did Reid observe in

his investigation?" "How can you explain the findings that Reid reported?" Finally, they would

read portions of Reid's findings, wherein they would encounter the idea and be exposed to the

idea of elastic rebound theory. Students would then discuss the idea of elastic deformation,

where they experience it and what it is, and how Reid's experiences as a glaciologist may have

played a role in his understanding of elastic deformation in rigid material. These ideas would be

written in their notebooks as well. This discussion would be followed by an activity focused

around the earthquake machine (see Figure 4). The purpose of this activity would be to

emphasize the nature of elastic deformation, the storage of energy as elastic strain, and the

randomness of its release.

   After these experiences, students would again answer the questions, "What is an

earthquake and what causes one?" The new information should be incorporated into students'

amendments of their original model. Eric would direct a class discussion by asking students to

describe their new models and how they incorporated this new data. This would help to align

students' ideas and give Eric a chance for formative assessment. Students would then explore the

nature of the energy released by an earthquake. Students would first describe their thoughts

about energy as it is released after an earthquake. Then they would watch video displays of the

US array of seismometers

(http://www.iris.edu/hq/files/programs/education_and_outreach/retm/tm_110823_virginia/GMV

_TA_Z_2011_08_23_175103.mp4 and http://www.youtube.com/watch?v=vxFtBWCNZ8U)

demonstrate the concentric nature of the energy as it is released; like a pebble dropped in still

water. Students were then to read about the history of developments in seismology from excerpts

from the United States Geological Survey's resource

(http://earthquake.usgs.gov/learn/topics/seismology/history/history_seis.php).

Once students had a familiarity of the development of seismometers, they were to explore data from the Rapid Earthquake Viewer (REV) (www.rev.seis.sc.edu) where, in small groups, they were to analyze seismographs for patterns of waves (hopefully discerning P- and S-waves, though not knowing their names). Students would review the videos from the US Arrays to see if they can discern the two waves. Students would work in small groups to study these videos and report and discuss their ideas with the entire class. Eric would then spend some time talking about and identifying the types of waves (body and surface) and their characteristics. Eric would then incorporate the slinky model of wave propagation to the class. He would demonstrate the nature of compressional waves and shear waves. Students would utilize this model to draw and write about earthquake waves in their notebooks and describe the strengths and limitations of the model. Another model to use is the gestural model having students stand and model wave energy traveling through earth materials (http://www.youtube.com/watch?v=jsVwVlU-qMQ). With this information, they can make sense of the "shadow zone" as observed on seismic wave travel-time graphs. This will be their first hints that seismic waves can be used to "see" inside the earth. This would be brought up later when talking about the structure of the earth's interior and how that might support or refute the various models to be proposed.

Having discussed the nature of earthquakes as a release of energy, the students would then answer the question of the cause of earthquakes. Where should one look to find the best evidence for understanding the cause of earthquakes? Students would hopefully suggest location, frequency, and magnitude as some of the variables to begin to study. Here, Eric would show a map (Mallet, 1857) of seismicity that students would use to describe patterns in where earthquakes happen and where they do not. Then students would discuss in small groups why

they think earthquakes happen where they do. Each model would be presented to the whole class

for critique against others' models.

Students would then read about the past models of earth dynamics in a packet of excerpts

of historic scientific articles and other material. The packet of readings included biographies of

the originators or main proponents of the particular model as well as some of the social context

surrounding the development of the model. The models include "porous earth," "contracting

earth" with the "land bridges" accompaniment, and "horizontal displacement." Eric would

introduce these models without giving judgment as to which might be better or worse models.

Students would discuss implications of each model as they relate to their model of earth

dynamics. In this way, students would be entertaining multiple working hypotheses, a staple in

geological problem solving. Their job would be to determine which model might be best at

answering the question of the cause of earthquakes, and what additional information they would

need to discern the reliability each of the models. Students, as a class, would rank the models

from better to worse, comparing strengths and limitations among all the various models,

including their developing, personal models.

After this work, the intervention shifts to investigate a new question. This question is the

nature of the energy needed for the phenomena explained by each multiple working model. In

the design of the intervention, I anticipated students' answers would include gravity, unspecified

heat, heat from inside the earth (radioactivity), earth's rotation, and energy from the atmosphere.

Eric would then ask students to express their models of radioactivity. Students would describe

their models and then read excerpts from Mullner (1999) about the history (and tragedies) of the

discovery of radioactivity. After the reading, students were to discuss social influence on

scientific investigations as well as the influence of science on society. Eric was to then

emphasize, through direct instruction, the chemistry of radioactive decay. He would inform students that with the discovery of radioactivity came the awareness of a heat source that could keep the center of the earth hot for longer than currently imagined, and also a mechanism for discerning the absolute ages of rocks. Eric would also bring up the idea of radioactivity, its role in WWII (atomic bombs), and the formation of the World Wide Synchronized Seismic Network (WWSN) whose purpose was to "listen" for nuclear bomb detonations. The systematic recording of data resulting from the network gave geologists an unprecedented view of the pattern of earthquakes around the world as well as information concerning the earth's interior structure.

Eric would also convey that during WWII, scientists began to gain a great deal of information about the sea floor. Readings by Hoehler (2003) and Lawerence (2002) would give students some of the history of seafloor exploration and, in particular, one woman's mapping of the seafloor, which began to turn the tide toward one particular model of earth dynamics over the others. Students would also be exposed to some gender issues in science as Marie Tharp was not taken seriously in her mapping of the mid-Atlantic ridge. At this point, students would be asked to do another activity, based on Sawyer (2002), and asking them to analyze different sets of seafloor data, including sediment thickness, geochronological, bathymetric, heat flow, volcanic and seismic activity. In small groups students would analyze this data, describe patterns, and then formulate explanations in light of their personal models and the historic models presented earlier. A new model of earth dynamics came with the discovery of the mid-Atlantic ridge. This model posed an earth that was expanding (Carey, 1976). As students discuss the strengths and limitations of each of the proposed models, they will begin to narrow down the possible choices.

Focus then would shift back to seismology as students explore a software program, entitled "Seismic Eruption." The program demonstrates earthquake occurrence though time by

plotting epicenters on a world map in chronological order starting from about 1960 to the present. Epicenter "markers" vary by size to reflect earthquake magnitude, and they vary by color to represent depth of event. Students also have the ability to focus in on specific areas by using the "draw your own map" option. They can choose the sensitivity of the play-back by setting the magnitude of earthquakes that can appear on the map (example: all events magnitude 3.5 and greater, or all event magnitude 7.0 and greater). Students can study the patterns of location, depth, and relation to geographic features. During this activity, students would ask their own testable questions and manipulate the different variables within the program to discern claims that would be supported by evidence and then see how the claims they derive relate to the various competing models of earth dynamics that have been part of the discussions to this point.

By turning on the "volcanic activity" option on this same program, students can explore the relationship between earthquakes and volcanoes. Students would then add this information to the models developed from the seafloor data activity, and again, look for the models that seem to explain the data best. Once student models have been refined via small group and/or whole class discussion, they were to read excerpts from Harry Hess's (1962) "geo-poetry" later termed "seafloor spreading." Students would be asked to check the alignment of Hess's model to the data and then check its alignment to the other competing models through small or whole class discussion.

The last set of experiences had students learn about paleomagnetism. This was the key that unlocked the answer to plate tectonics (Glen, 1982), Eric was to give a brief lecture on magnetism in rocks, where it comes from, how to measure it, and then show the different lines of inquiry within the field (polar wandering and magnetic reversals). Eric would also discuss the traditional geologists' circumspection to this relatively new discipline in geology (Oreskes,

1999). Of particular importance was the development of the timescale for magnetic reversals as more data were gathered and analyzed and technology became more sensitive, resolution of the scale increased (Glen, 1982). Students would see this in a progression of diagrams accompanied by a short reading from Glen's (1982) treatment of the topic. Finally, students would be given original diagrams from the Juan de Fuca ridge and just south of Iceland on the mid-Atlantic ridge that showed the magnetic anomalies on the seafloor. They would add this data to their latest models and compare to the data from the seafloor data activity. They would be asked to refine their mental model even further and see, of the competing models presented so far, which still explain the data.

Students would then read a couple articles that support Alfred Wegener's Drift hypothesis (Vine, 1963, 1966). They would also look for the metaphors that Vine used in the papers ("conveyor belt," "tape recorder," and "topographic scars") and comment on the how they influence the interpretation of the data. While discussing the reading in class, Eric would also bring up how Lawrence Morely tried to publish the same information but his paper was not accepted in two different journals (Oreskes, 2000) and discuss the implications of that with respect to NoS (who gets published, and why?). He would also discuss the idea that both Morely and Vine were physicists trained in geomagnetics, and had not been schooled in the way of the traditional geologist. Students would discuss how this might affect how they viewed the data, and how others (traditional geologists) might view them and their claims.

Of the models that are left unsupported by Vine's papers, students would be asked to determine what kind of data would be needed to support them to a better degree than the currently supported "Drift" model. Finally, students would be asked to view portions of videos on the internet (http://www.jamesmaxlow.com/main/index.php?&MMN_position=1:1,

http://eearthk.com/Expand.html, and http://www.nealadams.com/nmu.html) that portray the idea

that the earth is expanding. They would also view websites promoting what has now become the

theory of plate tectonics. Their task would be to judge the reliability of the claims made by each

model, giving critique based on the data and the models they had been putting together during

the entire unit. This would become their summative assessment for the unit.

The Best Laid Plans of Mice and Men Often Go Awry[7]

This section of the chapter outlines the factors that warranted the change in focus from

student model building to Eric's decision making. Despite our discussions of student-centered

discussions and activities, Eric insisted on maintaining a decidedly teacher-centered atmosphere

within the class. He viewed the intervention as an "extra" or "inserted" part of the course. This

departed from my intention for the intervention to be *the* instruction, not just supplementary to

Eric's regular teaching. Because I decided that my role as observer was to be as unobtrusive in

class as possible, I allowed Eric to have full control of the implementation during all classes of

the intervention. The problem of interest became the factors that influenced Eric to teach the way

he did despite its great contrast with the proposed instruction.

One of the main differences between Eric's usual mode of teaching and the mode of

teaching built into the intervention was the relative importance of direct lecture. Where the

intervention placed a greater emphasis on student-centered discussions and activities, Eric

perceived lecture being the prominent method of communication within the classroom. As a

result of perceiving the intervention as an inserted portion to his normal instruction and that

normal instruction being predominantly lecture, Eric perceived two distinct parts of class; the

regular part (lecture) and the intervention (do).

---

[7] From, "To a Mouse, on Turning Her Up in Her Nest with the Plough" a Scots poem written by Robert Burns in 1785.

> I'm going to check the schedule, but I think [the class] is two hours long, total. So what I
>
> am going to do is try to have lecture, and then do, every day. Lecture, do, lecture, do,
>
> lecture, do. (20120621:37-39)

Despite, his attempt to split time between his traditional instruction and the intervention, Eric spent much more time lecturing. For instance, during the first iteration, when introducing the earthquake machine, Eric was supposed to spend about 10 to 15 minutes setting the context for the activity. Instead, however, he lectured about Reid and his work and about earthquakes in general for about an hour and 20 minutes, giving students about 20 minutes to explore the earthquake machine, instead of the hour originally slated for the activity. He did give the class more time for the activity the following day, but in the end, the activity was never placed within the context of students building their own models, as intended.

> G: Yeah, so yeah, that was pretty good. So, I would think we could let them work on
>
> [the earthquake machine] a little bit more and then you can go into-
>
> E: The lecture? The lecture.
>
> G: Go into the lecture.
>
> E: Try to take what they've learned and say, "OK. This is how we talk about it."
>
> (20120611b:182-187)

From the above passage Eric showed that he was ready to start with students' results from the activity and put them into the context – "how we talk about it" – of current scientific thought. Instead of inquiry, students had a concrete experience sandwiched between two lectures that told them the meaning they should make from it.

There were many opportunities in the intervention for students to lead discussions, either in small groups or as a whole class. These would be opportunities for students to put forth their models and question the models of others; an important process in model-based learning. For this

reason, I placed seven microphones around the room to catch as much student conversation as possible. For instance, small groups would gather around each microphone to discuss certain aspects of the problem. The whole class discussions would also be captured by the multiple microphones and my own observations. However, Eric never gave the opportunity for students to author their own discussions, as was called for in the intervention. Instead, he thoughtfully and carefully structured the student discussions. In the following passage, Eric revealed the thought he placed into structuring the discussion so that students would get the most from the readings assigned as a precursor to engaging with the earthquake machine.

> We will first talk about Reid. ... He did analogies. He said, "Hmm, I've been studying glaciers, and what I've noticed about them is that they sit there, and sit there, and sit there, and sit there, and then break." Right? "And I've studied some other materials that just sort of don't seem to do anything, until all of a sudden they snap."… And then talk a little about bonds and talk a little bit about elasticity. What is elasticity? What does elasticity actually mean? … and how you tell whether something is strongly elastic or weakly elastic. And what do you think makes it that way? And then look at some of these videos and then checkout the website and, uhh, and then I will go into my lecture as far as I can. (20120611a:255-272)

Eric had obviously spent some time working out a trajectory for the discussion that would ensue when talking about a reading about the development of elastic rebound theory. The discussion that was called for by the intervention became more of a freeform lecture where Eric basically did all of the talking. He did ask questions of students on occasion, but when students were reticent to answer, Eric answered to follow the trajectory he had planned out already. Students never had the freedom to ask their own questions or critique each other's ideas. The recordings of class that were supposed to capture students' conversations during their model building

recorded only Eric's lectures and his structured discussions because the students had virtually no opportunity to talk about their thinking. The science notebooks students received to record their model development processes, recorded the notes that Eric wrote on the board or gave during his PowerPoint lectures. Students were not provided opportunity to record their thinking within their notebooks.

There were instances during instruction where students had more autonomy. This was during the two activities Eric implemented; the earthquake machine and the seafloor data activity. Despite the student-centered nature of each of these activities, Eric still maintained a structuring influence on student model building. For instance, during the second iteration of the seafloor data activity (Sawyer, 2002), students received multiple maps containing data sets such as heat flow, bathymetry, seismicity, etc. (see above description in this chapter). Not all groups had the same data sets, however. Students were to use the data they received in their small groups to develop an explanation of the data and then the groups would "jig-saw" into new groups where each new group had the complement of all of the data. This strategy created "experts" concerning certain portions of the data in each group, and their responsibility was to teach the others in the group what they knew. During this particular instance, after groups had changed, I observed a woman in her group begin to discuss her explanation of the data. She used arm gestures to model the geological process of subduction and discussed how this phenomenon explained portions of the data they were looking at. I was very impressed by the sophistication and description of her model. When I asked her how she had created her model, she said it was not something that she made up but was simply copying what Eric had just told her in her other group.

I became fascinated by Eric's decision making because it contrasted with the intervention in so many ways. I often expressed to Eric, when he solicited my take on the class, that he should

let students do more talking amongst themselves, and he agreed that he should. When in class, however, he never did initiate any student interaction at all. Even on the last day of the second iteration of the intervention, an event more fully described in Chapter 4, I suggested to Eric to pose a question to students and let them discuss it in small groups first. Eric did so, but within the matter of a couple of minutes he transformed that student-centered activity into a lecture about the answer to the question he had asked. I had given Eric all of these tools for teaching; tools that allowed students a lot of space to explore the meanings of the concepts they were supposed to learn. Yet, despite our conversations and my emphasis on letting students have some authorship of their concepts, Eric maintained his traditional teaching methods. Learning why Eric found it reasonable to teach the way he was, despite signals to the contrary, seemed to be a necessary task if I wanted to implement the original intervention in a way that more closely aligned with its purpose.

CHAPTER 5: FINDINGS

This chapter presents the analysis of conversations, interviews, and observations of Eric's teaching, as described in the last chapter. I present findings in four sections. The first is a brief introduction to Eric. The second section describes Eric's pedagogical context knowledge ($PC_{xt}K$) (Barnett & Hodson, 2001) in six themes. The third section recounts two motivations – authority and responsibility – that occur across the six themes described in section one. The final section ties the motivations together with Eric's $PC_{xt}K$ by demonstrating how Eric structured his decisions with two compound metaphors, the *puzzle metaphor* and the *fieldtrip metaphor*. The metaphors explain which tools of the intervention Eric used and how he used them.

Who Eric Is

The participant instructor, Eric, was a geology professor at the time of the study. In our first interview, I asked him to tell me about his experiences as a student and as a teacher up to taking his current position.

> Basically, I teach the way I cook…I love to cook. I have never had any formal training as a cook…if I make it so that I like it, then, somebody will like it…I try to teach the same way, which is sort of remembering back to those teachers that I found most accessible most interesting most informative, most effective, and trying to adapt what they did to the material I am trying to get across. You know how did I learn? How did they teach? What did I find to be the most effective set of examples? (20120611b:231-243)

Eric likened his teaching to his cooking. Though he had never had any formal training in either, he spoke of enjoying them both. He did mention that as long as he cooks the way he likes, then "somebody will like it." Following through with his analogy, he teaches what he finds important or interesting and it is up to students to be interested enough to listen to and learn from him. Eric also drew on his favorite teachers and the way he learns to help guide his teaching. Although he

liked the freedom to learn at his own pace, he also acknowledged a structure that kept him on track. He characterized his learning through "immersion" or "absorbing lots of information." from books, but did point out the possibility of "getting lost in the facts" and "not seeing the big ideas." The relationship between detail and big picture was an important part of how Eric defined his role and his expectations of his students.

Eric also attributed much of his teaching skills to experiences being a teaching assistant in many college level geology courses, holding a post doctoral position, and being a research geologist in a lab. In essence, he pulled from various points along his professional trajectory; student experiences, effective former teachers, teaching assistantships, post doctoral and research responsibilities. While a professor at his current university, he taught very large, lecture hall type classes. Teaching small classes such as the ones in this investigation was not the norm for Eric.

<div align="center">

Eric's PC$_{xt}$K

</div>

Despite the trend of many researchers to attribute teacher practices to their beliefs about teaching, learning, and science (see Chapter 2), I am using a model developed by Barnett and Hodson (2001), pedagogical context knowledge (PC$_{xt}$K), as a model to give meaning to the data reported in this investigation. I do this for a number of reasons. First, the multiplicity of definitions of "beliefs" (Jones and Carter, 2007; Mansour, 2009) as a construct remains problematic. Second, and partially due to the first reason, is results from that body of literature are inconsistent. Some have reported beliefs to be coherent, or "nested" (Tsai, 2002), where others have reported multiplicity and even contradictions among beliefs (Bryan, 2003; Kinchin, et al., 2009; Waters-Adams, 2006). Third, the results attempting to connect beliefs with practice have also been inconsistent. Though the reigning paradigm has been that beliefs are responsible for practice, very few studies have shown this to be the case (Brickhouse, 1990; Tsai, 2006). In

fact, where beliefs have not directly correlated with teacher practice (Hodson, 1993; Kang & Wallace, 2005), authors have invoked mitigating constructs such as tacit beliefs (Waters-Adams, 2006), teaching context (Jackson, 2011) and goals and intentions (Lederman, 1999). The construct of $PC_{xt}K$ allows for the obvious complexities among beliefs, practices, context, and other forms of knowledge that were part and parcel to Eric's decision-making. This research is not interested in delineating among beliefs, views, understandings, knowledge or attitudes as constructs in their own rite. It is looking for the meaning Eric made for different factors that held sway over his decision-making.

As described below, many of the factors that influenced Eric's decision making, his struggle between structured and free-form activities, the role of the text book, teaching with the end in mind, and the constraint of time, do not neatly fit within the construct of beliefs. I needed a more inclusive model for organizing my interpretation. Barnett and Hodson (2001) developed their model to understand teachers' views and the different kinds of knowledge they drew from while teaching. It is comprised of four separate but overlapping types of knowledge: pedagogical content knowledge, classroom knowledge, professional knowledge, and academic and research knowledge. These four types of knowledge appear superimposed upon "educational knowledge terrain" which is a subset of "societal knowledge terrain" (see Figure 3). In this section, I describe six themes from Eric's $PC_{xt}K$, namely structured (teacher-centered) versus self-directed (student-centered) activities, the certainty of scientific knowledge, teaching with the end in mind, the constraint of time, understanding of the textbook, and understanding of his students. Table 1 gives a summary of Eric's $PC_{xt}K$ as observed in the data and how these types of knowledge influenced him in his decision-making.

Educational Knowledge Landscape

- Teaching with the end in mind

Pedagogical Content Knowledge

- Structured or self directed
- Constraint of time
- Understanding of textbook

Professional Knowledge

T

Classroom Knowledge

- Understanding of students

Academic & Research Knowledge

- Certainty of scientific knowledge

Societal Knowledge Landscape
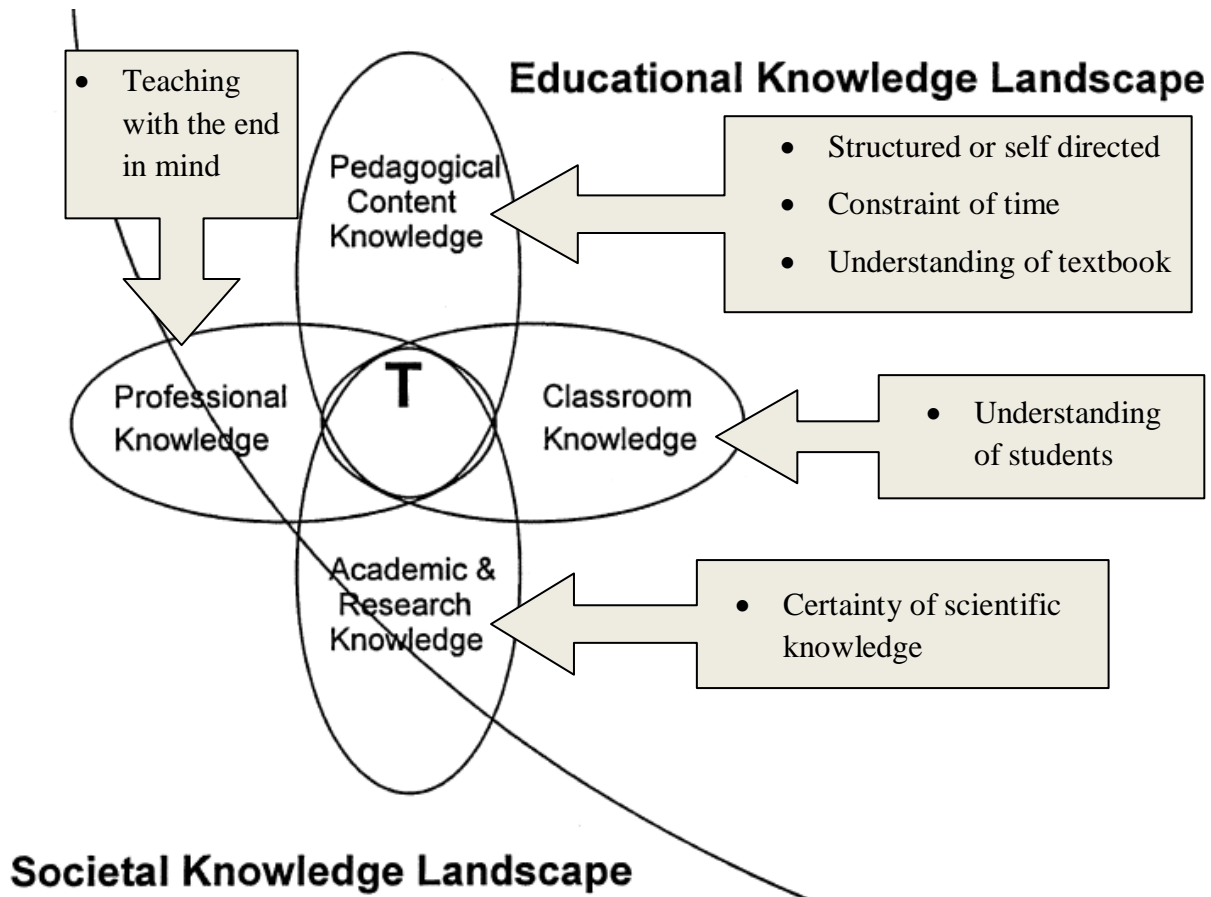
Figure 3. Representation of pedagogical context knowledge (PCxtK) and the six themes described in this section. **T** represents the teacher located at the intersection of four different bases of knowledge: pedagogical content, classroom, academic and research, and professional. The four knowledges are superimposed upon the educational knowledge landscape which is a subset of the societal knowledge landscape (Barnett & Hodson, 2001, p.437).

The Struggle Between a Structured Class and Student "Play"

Eric normally taught with traditional methods, i.e., PowerPoint-based lecture presentations, while stopping periodically to ask recall questions. The intervention design called for students to be active model builders: discussing and arguing their models with others, recording their ideas, models and model revisions in science notebooks, and developing, testing and amending models based on given and derived data. Eric often described these intervention activities as "self-directed," "free-form," and "play," and noted how he struggled to implement them.

For instance, in one activity, students used a model called the earthquake machine. The model comprised small wood blocks, attached by rubber bands. Students positioned the blocks on long belts of sandpaper and explored the relationship between friction, strain, and elastic rebound forces by pulling the blocks across the sandpaper with the rubber bands (Figure 4).
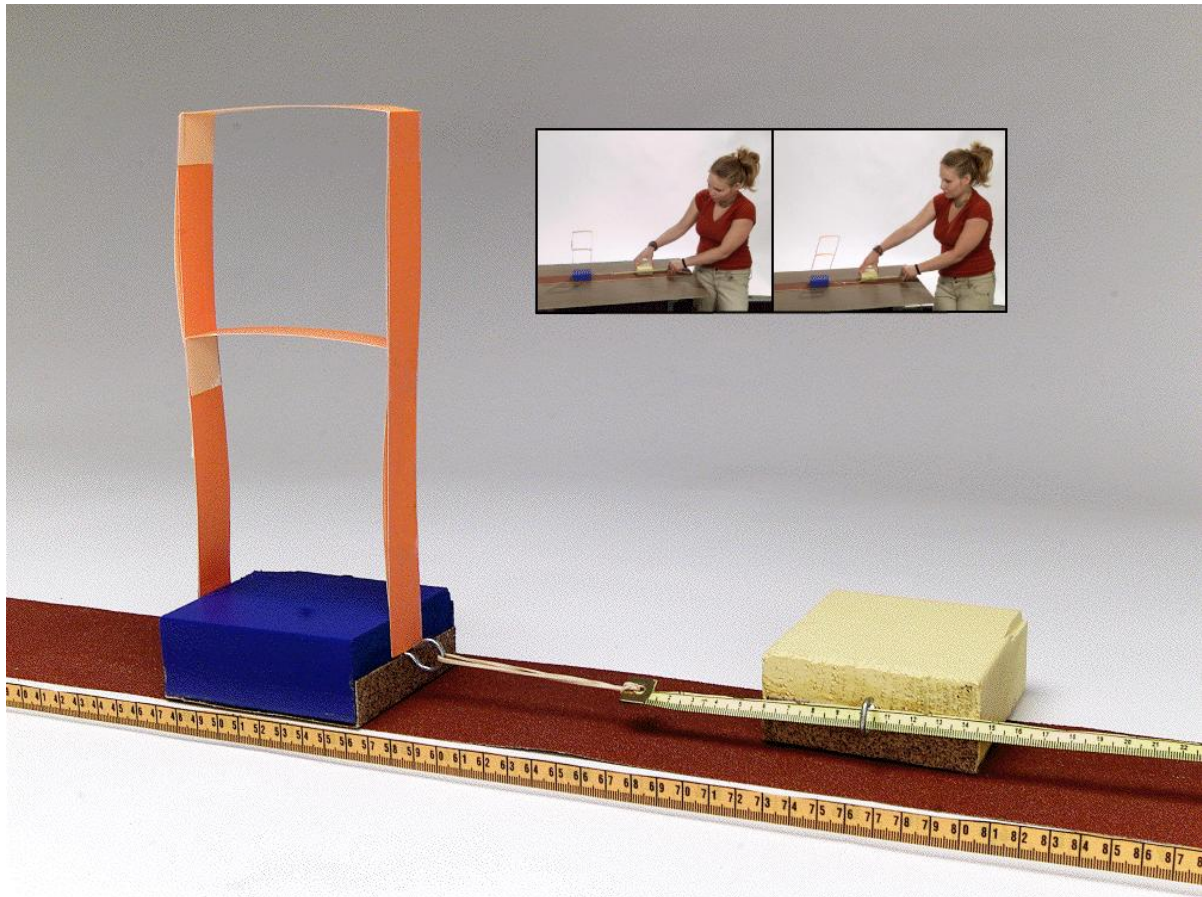
Figure 4. The earthquake machine. This model helps students explore the relationship between friction and strain in the context of elastic rebound theory. (Incorporated Research Institutions for Seismology, 2013) (http://www.iris.edu/hq/resource/redefining_an_earthquake_v12)

Prior to the first iteration, Eric asked about the earthquake machine as a tool for inquiry.

Eric: What are your implements of destruction over there?

Glenn: These are the earthquake machines.

Eric: OK. Are you going to set that up and play with it today? (20120605:149-

152)

Eric viewed the activity as, "we'll give them some toys," and "let them play."

In class, Eric described the idea of elastic rebound theory (Reid, 1910) that students had

read about and then introduced the model. He gave very little direction to the students for how to

utilize the model. They had rulers and rubber bands of varying lengths and thicknesses. They

also had other objects, such as small wooden centimeter cubes and rocks that they could explore

on the sand papered blocks. Students manipulated the "equipment" into multiple configurations

as they attempted to formulate relationships among all the different parts. The students struggled

with this. It was their first time since the course began two weeks prior that they had opportunity

to interact with each other. They had not done any other activities in class. Thus, this was new

and unfamiliar to them. Finally, because Eric's preceding lecture was longer than planned,

students had only 20 minutes to work as opposed to the hour the activity called for.

After this initial implementation, Eric wondered about the "free-formness of it" and if "it

is better to give a little more supporting informational material first or just let them play"

(20120611b:10-12). He considered this a "real conundrum." Eric struggled to negotiate between

the structure of lecture and the free-formness of play. He seemed unsure that by playing, students

would get the "basic stuff they need." The following day, before the students continued with

their explorations on the earthquake machine, Eric began class with some descriptions of what

the parts of the model represented in the context of earthquakes as well as giving suggestions for

set-up and operation. For instance, he used a long inclined plane to demonstrate one way to

demonstrate gravity, friction, and elastic rebound forces.

He was more comfortable structuring an environment, via lecture, to present appropriate material so the students could get it. Another example of this structuring occurred at the beginning of the first iteration. The intervention began with two eye-witness accounts of the 1906 San Francisco earthquake. Eric asked, "do you want to talk about P-waves, S-waves and surface waves first" (20120526:53-54)? He considered the eye-witness accounts "coming at [earthquakes] from a sort of personal entry as opposed to the science" (20120525:58-59). He distinguished between science - its discipline, use of vocabulary, and facts – from the personal accounts of two separate authors, Jack London and William James. To Eric, science was structured, impersonal and objective, whereas these two readings were qualitative, "personal" accounts, filled with the bias of each reporter.

The inquiry activities lacked the structure Eric was used to. There were no written directions, no formal worksheets, and no prewritten questions. Students worked in small groups writing down observations in their science notebooks and developing their models, also recorded in their science notebooks. He implemented two of them: the earthquake machine and the seafloor data analysis. During the first iteration, he implemented both with very little direction to the students. After the two experiences he had this to say:

> Uhh. It's also interesting flipping back and forth between lecture, discussion and
>
> play; trying to figure out how best to engage. It feels that they are getting a bit
>
> more comfortable. (20120611b:100-102)

As interesting as he thought play was, and as comfortable as he thought the students were, he wanted to add more structure to the activities for the second iteration.

> maybe make it a little more formal this time in terms of, "here's the earthquake
>
> machine, play with it. And now let's actually make some measurements, make

some hypotheses, test those hypotheses, make those connections… Yeah?... "OK.

Let's try and put them into a little more structure this time around."

(20120705:215-233)

Similarly, he spoke of making the seafloor maps activity "more formal" and "disciplined" by having students make hypotheses and test them. In his view, there was a difference between self-direction and the discipline involved making and testing hypotheses; "playing," and behaving like a scientist. To address his concerns, we created documents for the second iteration that allowed some choice of action for the students, but formalized what they should observe and how they should record their data. For instance, we went from verbal instructions describing the type of data they had and asking them to look at the maps and discern patterns, record what they observed, and to formulate explanations, to more formal written directions such as:

> This could include diagrams and **descriptions** of your data. Try to develop some
>
> **explanations** for the patterns you discern as well. This could take the form of
>
> "these types of locations always seem to have this kind of data" (**description**).
>
> This could happen because…" (**explanation**). This is also a good occasion to
>
> draw diagrams. (emphasis original)

Similarly, we asked more directed questions to focus their thinking about the investigations.

1. **List** what you learned about ocean basins that you did not know before.
   Be specific.

2. **Describe** the experience of developing descriptions and explanations from
   data and then sharing your descriptions with those who had different data.

3. Most of the multiple models of earth dynamics that you read about were developed prior to having much understanding of what the seafloor looked like. **Discuss** how the models stand up to the new data.

4. **Develop** your own model for earth dynamics utilizing all of the data you have so far as well as any bits and pieces of other models that might seem useful. (emphasis original)

Eric thought that students were not really prepared to participate in and gain understanding from "free-form" activity, or play.

> Umm, I think it is interesting to me, the free-formness of it… I think that they- the students don't necessarily- they don't necessarily quite get the lack of framework yet… (20120611b:10-12)

To Eric, students lacked the background or the experience to take advantage of free-form activities. On the other hand, Eric equated free-form activities, or play, as giving up control of the class.

> learning, you know when to grab control, you know, like, it's like saying, "OK now we are going to do this. And I am going to teach you this. And you're going to listen," and then letting go and saying, "OK I've told you about that now let's play with it. (20120611b:267-271)

Even play needed a pre-emptive structuring before letting go. One reason for this is Eric perceived that without the structure, students would not know what they were doing, become frustrated, and flail. He stated, "at the intro level it's sometimes difficult to have self direction work. It's too easy to let them flail," and flailing amounted to wasted time.

Part of the structure Eric included in class was background material. He thought students struggled in class because they lacked background, experience, or a tool box. They needed this tool box to generate questions during inquiry activities, to make connections among the scientific information he gave them in class, or to be self directed.

The thing that I think is happening is that because they don't have enough

background, it's hard for them to generate the ideas…Does that make sense?

They don't have the tool box yet. (20120611a:38-44)

In Eric's view, if students were not able to generate ideas, they would be frustrated. Structuring instruction to incorporate background material was Eric's way to mitigate flailing and save time.

Eric's memories of being a student paralleled the decisions he made. He said that as a student, he enjoyed both structure and freedom in his learning environment.

…an order or structure that allowed me the freedom to learn in my own way and

my own pace, within a structure that kept me on track to get me through the

material. (20120611b:241-243)

Eric's frequent comments about giving students ideas and having them make the appropriate connections reflected his experiences of having freedom in structure. Based on Eric's understanding of the universality of scientific knowledge (discussed next), once students received the information, they actually had little freedom to put the ideas together because there was only one correct way to do it. The science was "ready-made" (Latour, 1987).

Despite Eric's doubts that students would get what they needed from playing, he did perceive the freedom of play as a tool for engaging students.

If I can, you know, get twenty students out of two hundred, you know, interested

and engaged at that level, great…if it takes, you know, dropping the book for a

little while and playing with pieces of wood that's what I'll do. (20120611b:390-

394)

In all, Eric saw the benefit of "playing" in science class. It garnered engagement. However, there

was little else. Students needed a certain amount of background and experience to be able to play

effectively and he was doubtful students would learn the fundamental knowledge they needed to

be successful in the class and beyond through play. Eric found comfort and predictability in the

structure and certainty of lecture. Structure helped him as a student and it would help his students.

The Certainty of Current Scientific Knowledge

When Eric talked about scientific theories, he categorized them into two groups: wrong

models, or "what's really going on." For instance, when discussing historic models in class, Eric

qualified them as wrong, because they were different from the current scientific understanding of

earth dynamics.

…talk about some models of the earth going back to Aristotle, right? Porous earth,

expanding earth, contracting earth. Focus being, "hey these guys were not stupid.

Right? They were not crazy. Why is it that they came up with ideas that were

wrong?"...So, what- what can we do with them [students] to guide them towards

this idea of taking good data, good logic, incomplete view? Right? Incomplete

hypothesis, right? (20120705:291-301)

Eric had to qualify these scientists as "not stupid," even though what they created was wrong, or

at best, incomplete. Eric thought that with good data and good logic, students should be able to

get the correct scientific idea.

In contrast, the intervention introduced historic models as competing and equally viable models in need of scrutiny. Eric did make an exception with Wegener's theory of horizontal displacement of the continents.

> It's like Wegener. Right? He really did get it. But he didn't get all of the if-then statements that got him from that starting point to the finishing point. (20120620: 52-54)

Traditionally, many view Wegener's theory of continental drift as the springboard to the current theory of plate tectonics. It explained otherwise aberrant observational data – paleontological, paleoclimatological, and geological – by claiming horizontal displacement of the continents. Other explanations supposed vertical motions of the crust. However, Wegener's description of the physics and mechanism of the movement were just as "wrong" as the other models. Within the context of the current scientific explanation, it was easy for Eric to consider that Wegener really did get it. Eric identified good logical thinking and properly directed investigations, as witnessed through the history of the theory, to verify Wegener's initial assertions. The end point of investigation was inevitable.

> there's a big picture, and that big picture has to do with the shapes of the continents, and once we started looking off shore; understanding how the system worked in total, then we really saw this picture of plate tectonics…so let's talk about the progression of ideas and now go into what we think is really going on…It's like those 3-D pictures…once you know how to look at it…
> (20120712:66-79)

Eric likened scientific truth to a "magic eye" picture. "Magic eye" pictures are a type of stereogram containing a three dimensional image, camouflaged in a two dimensional computer

generated pattern. It is just a matter of looking at the pattern (the data) in the correct way to see the hidden (whole) picture from the details. Eric likened this to having the same answer to many different questions. For Eric, this showed "you are on to something basic. You are starting to get at the heart and soul of this particular system" (20120809:197-198). Eric perceived the repeated answer as the cause of the phenomena, as opposed to a construction to explain observations. Eric saw these truths as the objective, universal, collective product of the scientific process.

> Part of that is my own bias because of how I grew up and why I got interested in science. But I think, based on what I've seen, that, you know, coming at it from the physical body of understanding… (20120611b:438-441)

Eric's holding to the certainty of scientific knowledge and traditional lecture-style teaching indicated an objectivist epistemological stance with regard to science and science teaching and learning (Bartholomew, Osborne, & Ratcliffe, 2004; Sfard, 1998). Those holding an objectivist epistemology interpret the world like this:

1. The world is made up of objects with properties independent from any beings.

2. Our knowledge of the world comes from experiencing those objects.

3. We categorize objects based on properties we consider inherent to the object.

4. Objects make up reality and science is a way through human bias to realize that reality.

5. Describing reality requires words which have fixed, precise, and absolute meaning.

6. Communication is perfect with the use of precise words with absolute meaning.

7. Objectivity allows us to rise above our human biases and see absolute truth.

8. To be objective is to be rational. (paraphrased from Lakoff & Johnson, 1980, p. 186-188)

The implication of objectivism for Eric was that teaching was quite easy. Since a scientific truth was real and universal, learning about it only required exposure to the evidence. The data speak for themselves. It would naturally make sense.

> We will give them some toys, some data, some information and try to see if
> they'll come up with, "Oh look, here we've got shallow earthquakes and here
> we've got a deep line of earthquakes going down into the earth, and here we've
> got earthquakes and volcanoes in a line, and here we have earthquakes only in this
> area around the mountains, and here we've got these spots of earthquakes and
> volcanoes and they are all arranged in a line. (20120705:279-286)

For Eric, the truth of the cause (plate tectonics) was so obvious that given maps of seafloor data, students would automatically pick out the appropriate effects (earthquake patterns, volcano patterns, mountain locations, etc.) This leads into the next theme.

Teaching with the End in Mind

During the first iteration, when students initially experienced the earthquake machine, they only had about 20 minutes to explore with it. During our conversation after the class, we planned to give students a bit of time on the following day to continue with their investigations.

> Glenn: Yeah, so yeah, that was pretty good. So, I would think we could let them
> work on it [the earthquake machine] a little bit more and then you can go into-
> Eric: The lecture? The lecture.
> Glenn: Go into the lecture.
> Eric: Try to take what they've learned and say, "OK. This is how we talk about
>   it." (20120611b:182-187)

Similar to the distinction he made between "personal" and "scientific" above, Eric emphasized the importance of lecture for putting student observations into the context of current scientific thought. Missing from this approach was acknowledgement that the current understanding had to be built, that the current model was not obvious to the scientists at the time who studied the data. He wanted to introduce the new information so it would make sense to students within the context of plate tectonics; presenting ready-made science. I refer to this common (Bartholomew, et al. 2004; Sfard, 1998) teaching strategy as "teaching with the end in mind."

An exemplar of teaching with the end in mind was Eric's lesson concerning "how we know the earth has layers." This lesson was a full class period (about 2 hours) description of the history of our understanding of the internal structure of the earth. Eric started with the Greeks realizing the earth's spherical shape and Eratosthenes being able to measure its size based on that assumption. Once a size had been calculated, it was a matter of using Newton's equations for gravity to calculate the earth's density. The results of that calculation were over twice the value of any rock sample found at the surface. This meant that the interior of the earth must be denser than those rocks. Finally, the interpretation of seismic wave signals helped scientists to discern layering of the earth. The description made a wonderful and engaging story. According to this rendering of science, the direction of the path of scientific discovery was purposeful and ended logically at our current understanding, as if the explanation was waiting to be discovered rather than built by scientists.

> I think they're starting to really, hopefully, you know, get that a lot of this stuff is really simple. You know, like I was saying if you get a spring, with a known weight, and you walk around and measure how far the spring stretched, it really is that simple. (20120618:61-65)

This story expressed scientific discovery in hindsight. For Eric, it was easy to see the logic and simplicity in the scientific process. This also came out when Eric referred to wrong models or incomplete hypotheses. "Incomplete" implies knowledge of more; something that can only be known after the fact.

Allchin (2002) critiqued Duschl (1987) for this same retrospective approach to teaching science based on its history. Duschl asked students to use earthquake data to pick a correct model for earthquake generation from multiple historic models. However, students already knew which model was "right." According to Allchin, this type of activity taught students how to rationalize the correct conclusion with data as opposed to reasoning an unknown conclusion from the same data. In the intervention, because Eric knew the "right" answer was plate tectonics, he could, and did, express to students only the data that supported the theory and rationalized plate tectonics from the data rather than letting students use the data to reason a possible explanation.

For Eric, plate tectonics was the context in which he talked about the observations made in nature.

> …why are we studying this and who really cares about meandering rivers and the
>
> deposits they make? Right? Oh wait a minute, now I understand, because when
>
> the plates move and base level shifts, then the river changes its behavior and it
>
> leaves behind a record of that change that we can see when we look at the rocks.

Eric wanted his students to rationalize observations such as base level changes as an effect of moving plates, which cause changes scientists can predict and observe. He wanted them to see how the "pieces…start fitting in that framework" (20120705:489-490). The framework was ready-made and determined how the pieces of knowledge fit. Eric viewed the purpose of the

intervention in this manner. When discussing a change from the traditional order of laboratory

experiences to one starting with plate tectonics, Eric told Paul (the GTA):

> Eric: …the idea behind this actually is that plate tectonics is the entire
>
> framework of how we understand this stuff.
>
> Paul: So you'd rather do- do you want to do plate tectonics before minerals?
>
> Eric: Yes.
>
> Paul: OK.
>
> Eric: Umm, we're going to do… we're going to do tectonics before
>
> minerals…the idea is to give them the big framework that everything will fit in as
>
> we go along. (20120705:373-387)

This was why Eric added the structure of background information for his students, as described

above. He said students had difficulty because they lacked the background that would provide

the structure, or framework, in which the information from class would fit. The background,

putting the pieces together, as with the story of the layered earth, would be a logical, even simple,

task.

> It always relates back to the tectonic setting. And if they have the concept, if they
>
> have that, A, that concept itself and B, if they know how it came about, and they
>
> know why it is we look at the shape of mud cracks when we are thinking about
>
> plate tectonics, right? Because, the shape of the mud crack tells you which way is
>
> up. Well, what else tells you which way is up? Oh wait. Magnetic minerals tell
>
> you which way is up. So there is, there is really simple, like, you know, what
>
> direction is it? And what shape is it? And how strong is it? That then ties back

together. Trying to lace all of that together is very difficult if you wait until the

end to spring the plate tectonics on them. (20120809:298-308)

Plate tectonics is the cause of effects such as deposition creating mud cracks or magnetism in

some rocks and the change in their orientation after emplacement. Therefore, students can easily

and logically make sense of them in the context of the cause.

This particular theme is important to this study because it opposed the intervention's goal.

The structure of the intervention had students use given and derived data and competing historic

models as stepping stones to building their own models of earth dynamics phenomena without

the benefit of hindsight. They, like the originating scientists, were supposed to "grope" in the

uncertainty of extraneous data, bias, new models and explanations that needed testing and

arguing. In the intervention, the students were allowed the freedom to build "wrong" models.

Students were to struggle in the "process" of science, where they develop, test, and refine a

possible answer. By teaching with the end in mind, the process of creating their scientific

knowledge was sacrificed for the process of rationalizing a known conclusion; justifying

someone else's "right" answer. In the method called for by the intervention, there is no endpoint

to investigation. There will always be something to test, as scientists still researching in plate

tectonics will confirm. Students' models are "works in progress." By teaching with the end in

mind, there is no need to extend investigations further than the given "right" answer, because

there is nothing left to investigate.

The Constraint of Time

This part of Eric's context was an influence external to Eric. While the prior three were

Eric's inherent understandings of science and teaching science. Teachers often defer to time

constraints when discussing why they do not implement innovative instructional interventions

(Höttecke & Silva, 2011; Orion & Ault, 2007). Similarly, Eric viewed the intervention as "fitting in" to what he was already doing; extra to the course content. Describing the intervention's relationship to the course, Eric told Paul, "So, [Glenn] is going to be to be doing- we talked about this a little bit. [Glenn's] doing sort of an inserted module into this course… (20120705:276-279).

Eric often expressed the struggle with teaching in a regular 15-week course. "You know, this is the stuff that you want them to learn and understand, but on the other hand, honestly, college classes are too short" (20120614a:119-121). The implementation occurred in two six-week long summer courses. This emphasized the constraint of time even more. In his last interview, Eric acknowledged the fact that the course was "massively accelerated" created problems with the intervention.

> One problem with the unit [the intervention], which is not necessarily the unit's problem, is the amount of reading is large for the time span of a college semester course. The time crunch is a real issue…that's a real toughy. Getting through that material quickly enough that you can still do the rest" (20120809:36-42).

Eric utilized about 30% of the readings, with modifications taking place for the second iteration by replacing larger readings with summaries and more diagrams. When I asked Eric whether he thought there would be time in a regular 15-week course for the amount of reading, he was still reticent, and again acknowledged the intervention's perceived extraneous nature with, "it's not a history of science course." In other words, not only would it not fit, but it also should not supplant the regular material.

The second iteration incorporated shorter readings. Eric also asked that the activities be "streamlined from what we did last time around so that it fit into one week" (201120705: 132-

133), instead of two. This included the addition of structure to the labs. Eric suggested that Paul and I "work together to make [the activities] a little bit more directed. So it goes a little faster" (20120705:326-328). This included the addition of directions and guiding questions as described above.

Eric's Understanding of the Textbook

Based on Eric's understanding that scientific knowledge was objective reality, he granted a great deal of authority to the textbook. It was a holder of the information. He expressed this by organizing the course around the order of topics as they appeared in the book. The two different courses used two different textbooks. Eric said the content of each book was "virtually identical," and the only real difference between the two books was the order of the topics. In the first course, the plate tectonics chapters occurred in the middle of the book. For the second, they occurred at the very beginning. Although Eric maintained ultimate authority to rearrange the schedule, he did acknowledge the text by qualifying that his plan was "a little out of order from the book," and "not [being] particularly worried about it." He did, at times express instances where the text book caused him to feel "forced into to a box as to what to teach."

Eric said students needed to have a text to know that the course material had a basis in reality. He seemed to consider they held the textbook in the same regard he did. He asserted that students counted on the text for a feeling of security; that they granted a certain authority to it.

> and maybe this is unfair to the students. But if the students don't have a text book, they will lack an anchor, they will lack the ballast; that little security blanket…at least reassure themselves that the stuff they are thinking about and the things they are learning have a basis in reality. (20120809:434-440)

Eric saw students needing the textbook to give weight to the class; what Eric referred to at another time as "gravitas." They could look up information in the text, and they would "be a little bit lost" without it. In a way, he thought students relied on the text as a "crutch," because it contained the information they sought. He did acknowledge it was a crutch for him as well.

Eric's Understanding of His Students

Eric defined three types of students: the good, the bad and the middle. To him these designations arose from an inherent quality to the student. The good students were receptive to the knowledge he was imparting - interested in learning "at a deeper level." The bad students were not receptive.

> I saw this on the test, a few did spectacularly on the test, and a few people did
> spectacularly bad…The ones who did spectacularly bad are the ones who don't
> come or fall asleep…Yeah, right, you didn't do the reading and you are not
> paying attention so it doesn't matter how good the teacher is, or not.
> (20120618:53-61)

The reason these students did spectacularly bad was because they inhibited the transfer of objectively real knowledge by not coming to class, doing the reading, or paying attention. Eric described the student in the middle as having disinterest and only wanting to receive information, "write it down and give it back."

Eric also identified this inherent quality or receptivity as their willingness to engage. While planning a class that would be more discussion oriented, he asserted "the way I want this to go, again, combination discussion lecture, but maybe a little more discussion, if they are willing" (20120713:9-10). In contrast, he knew students were no longer receptive when he

recognized their eyes "glazing over." At this point it was time to "shake things up" and "grab control," or just "let them go get some sun."

After receiving the knowledge, Eric regarded students as storage for that knowledge. He wanted to help students build a "memory palace" for storing "the names of things and specific equations and specific details" (20120809:30-32). He also talked about students having a library full of facts, "…at least they are starting with a framework in which they can begin to hang that library full of facts; to shelve those things" (20120809:223-225). Whether it was a memory palace or a library of facts, Eric viewed his students as the repository for the information he gave them. An important facet of this stored knowledge was the background material Eric thought his students needed. This was the toolbox they needed to understand the course material.

These PC$_{xt}$K themes held sway over which tools Eric picked, drawing from both his repertoire and that of the intervention, and how he implemented them. Due to the relationships among the themes, for instance, objectivism favoring teaching with the end in mind and more structured activities alleviating the "time crunch," Eric often drew from multiple themes to make or rationalize a decision. One example occurs in the following passage concerning his perception of the earthquake machine, and how he wanted Paul and me to direct it.

> So, one of the things that I would like to do is he has got a couple of exercises,
> umm, that are you know sort of, there is a little bit of, there's a free-form. Like,
> "OK here's some toys," right? The earthquake machine…Strips of sandpaper;
> blocks with sandpaper on one side. Rubber bands. Dit. Dit. Dit. Dit. Right? See
> what happens. Right? The first part of it is, "Here's the stuff. Play with it." And
> then I'd like you guys to work together to make it a little bit more directed. So it
> goes a little faster. Umm, which is measure these things make some predictions

write this down as if you were a scientist trying to figure out how this works.

(20120705:319-330)

Eric viewed the earthquake machine as a toy students would play with, in a free-form activity. He suggested making it a bit more directed. Eric wanted structure because it was more scientific. This would facilitate students getting what they needed in a more timely fashion. It was a way to streamline the intervention so it fit into the week-long time frame. He wanted students to "measure these things," because he was teaching with the end in mind, and knew what data would be most appropriate to "figure out how this thing works."

$PC_{xt}K$ (Barnett & Hodson, 2001	Eric's observed $PC_{xt}K$	Influence of Eric's $PC_{xt}K$ on his teaching
Academic and research knowledge	Certainty of scientific knowledge	Because current scientific knowledge is objectively real, transmitting to students via direct instruction makes most sense.
Classroom knowledge	Understanding of students	Good students are interested and receptive to transmitted knowledge. There is no need to negotiate meaning, no reason for two way communication or student creativity.
Professional knowledge	Teaching with the end in mind	Stories rationalize data in terms of the answer already given. Deductive reasoning over inductive.
Pedagogical content knowledge	Structure vs. self-direction	Self-direction has perquisite background knowledge. Without proper background information, or appropriate structure students will "flail;" halting learning.
	Constraint of time	Course is "massively accelerated." Little time for "extra" or "inserted" material. Streamline and structure the second iteration to save time.
	Understanding of textbook	Textbook is a "crutch" or "security blanket." It is an authoritative resource for transferring knowledge.

Table 1. How Eric's $PC_{xt}K$ influenced his instructional decision making.

Eric's Motivation

Where the themes described above illustrate the different types of $PC_{xt}K$ Eric relied on to make his decisions, this section describes two factors, Eric's authority and responsibility to his

students, which were integral for giving purpose to his decision making. In other words, Eric's

$PC_{xt}K$ shaped the choice of tools and their use, whereas the motivation made choice making

necessary. Often these two motivations worked hand-in-hand, with Eric's authority usually

leading to his responsibility to his students. As above, I have tried to tease the two constructs

apart for clarity.

Developing a Sense of Authority

Eric expressed his sense of authority often during the intervention. With authority came

an awareness of having influence, or control, within the class. It also encompassed being an

expert, confident of what he was doing and saying. Because he was the holder of knowledge, he

had the authority to distribute that information in a manner consistent with his $PC_{xt}K$. Eric

developed his sense of authority while a GTA, teaching undergraduate geology laboratories. He

had little direction about teaching when he began.

> [Shakes head] they just said, "here's your lab. Teach it. And here are previous
>
> laboratory materials. Here are the previous instructor's notes," you know, "ask the
>
> instructor for advice in how to teach this best." (20120611b:229-231)

This was challenging to Eric. He mentioned having a sense of discomfort at directing class with

this type of preparation. Eventually he realized, "one of the ways to overcome that sense of, of

discomfort was to talk about my experiences; what I've done, where I've been, what I've

experienced, where I've come from, who I am" (20120611b:256-258). Eric realized the way to

gain a sense of control, his sense of authority, was to *tell* students about what he had done and

what he knew.

> "Here I am. I've done this interesting stuff. I know these interesting things, and
>
> I'd like to talk to you about them. But I do know more than you, and I have done

more than you, and you should probably spend a little more time listening to what

I have to say"…"OK, I've completely lost their interest. I've completely lost any

control. Now what do I do?" (20120611b:260-276)

Eric's sense of authority rested in his knowledge and experiences, and also developed from

student expectations. "Part of it is the expectations of a class. 'This is a class, and that is my

teacher, and my teacher will teach me what's in the class'" (20120614b:19-21). For Eric, his

knowledge and his students gave him the authority. He embodied the authority by garnering

student interest and maintaining control.

 It seemed the authority his students granted him was also responsible for a "barrier of

respect" they maintained between them and him. He defined the barrier in different ways.

…there is a barrier. It's a knowledge-based barrier, it's an experience-based

barrier, it's an age-based barrier. It's there, and trying to get communication

across that barrier to come freely and openly, you know, once you've convinced

them that you will not be judging them as people, once you've assured them that

getting the wrong answer is not going to mean that they fail. (20120809:643-650)

Eric saw the differences between him and his students (knowledge, experience, and age) as

grounding for the authority he assumed. Because he had the authority, he was in charge of

determining whether students were right or wrong, causing student reticence to contribute in

class. "They don't want to disappoint me, who just spent, you know, three days of two-hour

lectures trying to get this point across and failed, apparently" (20120809:659-661). From his

GTA experiences, Eric maintained his role as authority in class as telling his students (three days

of two-hour lectures) about the material they were supposed to learn. He had the knowledge and

had the authority to give it out to his students. Students were the recipients of the knowledge and

should understand what he was teaching. However, when Eric posed a question, oftentimes an

"uncomfortable silence" ensued.

> The uncomfortable silence comes about when someone in the know, that would
>
> be me, is presenting essentially what for me is a rhetorical question. And what I'm
>
> doing, what winds up happening is there's this, there's this feeling like people
>
> know they should know the answer. I know they should know the answer,
>
> because we just talked about it, and what I am asking them to do is, is give me
>
> that answer and connect it to the larger topic that we've been discussing in a way
>
> that shows what is going on. (20120809:622-629)

Based on Eric's objectivist context, effective communication should be effortless. Students

should know the answer from them having just talked about it. Eric also referred to "failure

worry" as part of the discomfort he felt during the uncomfortable silences. He questioned his

efficacy in getting the information across to students. Eric often ended the uncomfortable silence

by telling them the answer. He regained control of the class and his authority by disseminating

his knowledge.

> We discussed my role in the class during the intervention period. Eric did not know if I

wanted to implement the intervention. "Are you looking for them to see you as a teacher, an

instructor?... so, you want to stay observer level…Or, TA level…I'll maintain the authority in

the room" (20120605:170-191). When I told Eric that I wanted only to observe the progression

of the intervention, he identified that as observer or TA level and said he would maintain the

authority. He maintained this authority through the delivery of lecture. It was a way he could

have control over the class. This authority also allowed him a sense of control over student

behaviors outside of the classroom. When we discussed sending out the readings for the second

iteration, Eric suggested I send them out electronically to the students. Then he changed his mind. "Why don't you let me do it?...That way, that way it's coming from me" (20120705:168-170). It seems he thought students were more likely to take the assignments seriously coming from the authority of someone at the instructor level rather than someone at the observer or TA level.

Responsibility to His Students

Eric also expressed a sense of responsibility for his students' learning within the constraint of time allowable in the course. This responsibility manifested itself in Eric's decisions, most often in his use of teacher-directed activities. In Eric's view, this kept students from becoming frustrated and flailing and was more efficient in getting the "basic stuff they needed" to them. As discussed above, Eric struggled between structure and letting them go. This may be because he was conflicted in his responsibility. He had a responsibility to teach the students. He utilized structure to meet this responsibility, but he acknowledged structure was not really engaging. Eric considered student engagement another responsibility. Finding a way that was different from lecture to foster student engagement was why he was interested in participating in the research.

> Oh, I am always, always, always looking for better ways to get the students
>
> engaged at a level that is simply beyond, "I need to learn this to get my – I need to
>
> learn- I don't even need to learn it. I just need to get a credit." (201200611b:348-
>
> 351)

For Eric, these two did not seem to be reconcilable. He could "put down the book and let them play," but he doubted this would result in learning, or he could "stuff their heads full," knowing that engagement might not be high.

Eric enacted his responsibility when he asked to change the format of the readings for the second iteration. Eric thought the historic readings were too dense and long. He wanted to do some of the work for his students by changing the intervention readings into summaries with diagrams instead of the original historic text.

> I think bringing [the texts] into modern plain language, summarizing with key
>
> quotes, and, you know, sort of a simple break down. And it would be doing a lot
>
> of the work for them, but again the point here is not to necessarily educate them
>
> about those models but to educate them about how this process works and why
>
> the wrong ideas are often so important. Right? (20120614b:42-51)

Eric saw the advantage of the readings in educating the students on the process of science and not about the wrong ideas resulting from the process. This was another example of Eric's responsibility; to teach only the correct version of science. Because of his idea that historical scientific models were wrong, the idea of using them as teaching tools did not set well with him. Eric illustrated this when he commented on a book written about the expanding earth theory. While flipping through the book, Eric noticed some of the conjectures the author made, including that subduction was not happening and that the growth of the planet has been increasing exponentially since the breakup of Pangaea, about 250 MA. Eric responded:

> E: Oh my God. We are not teaching this book to my students.
>
> G: No. No. No. No.
>
> E: OK. Good. I will not do this to them. This is malpractice. (20120526:679-
>
> 681)

Eric deemed only current scientific models, what I have been referring to as ready-made science, as correct and what he was responsible for presenting. This parallels Höttecke and Silva's (2011)

description of the "culture of teaching physics," where the teacher's role is having and conveying the truth of the content. Eric perceived teaching about the wrong, historic models akin to "malpractice." He had a responsibility for his students' intellectual well-being.

Eric's responsibility to teach the correct models also influenced his ideas about using the textbook. At times he was quite critical of the text because he thought it was deficient.

What I mean by that is that introductory textbooks…contain a lot of highly simplified, presumptively foundational material. And yet…fundamentally wrong. (20120809:681-685)

You know, you know, it's really hard when you are sitting there writing a diagram on the board and you show these relationships [from the book], and you know it's not exactly like that. And there's this fine detail, and there's that fine detail, and there's this caveat, and there's that corollary, and all of a sudden, you've got the students looking at you like, "we didn't even understanding the first part. What the hell are you talking about?" (Both laughing). (20120809:712-735)

Eric described the challenge in teaching novices the geology from the book, which is presumptively foundational material while knowing all along that parts were fundamentally wrong. He knew his authority gave credence to what he was saying and he had the responsibility to give them accurate information and keep them from getting confused or lost in the fine detail. Similar to summarizing and simplifying the historic readings, Eric's responsibility lie between giving them accurate information but, at the same time, not getting them confused. He also felt responsibility to use the book, despite its flaws, because "the students have already paid for them."

The manner in which Eric expressed responsibility to his students at times depended on the perceived needs of the students. For the "good" students, his responsibility was to impart skills to them for thinking on a higher level, taking fine details and making big picture connections. He had a different action for the students he identified as "bad."

The students at the bottom end of the spectrum. What are you going to do? Right?

I mean you try to get them into class? You try to get them a number of

opportunities to get enough points to get the grade they need to get their credit

and then get out. Because it is not what they are interested in. (20120809:577-580)

He acknowledged his responsibility to get these students through the class; give to them enough opportunities to get credit. He talked about having to push students to make conceptual leaps, or needing to pull them into various topics. In the end, he did acknowledge that despite his responsibility to get them through the course, final success was up to the interest of the individual student. He stated, "the gyrations that you put yourself through as an instructor don't matter as much as how hard they work and how much they care. And you can't make them care" (20120809:563-566).

To sum, Eric's sense of authority and responsibility acted as motivations across all of the PC$_{xt}$K themes. With respect to his struggle between structure and the free-formness that the intervention called for, Eric utilized structure, mainly in the sense of direct instruction, because it was in line with his perception of control, to be in authority. Eric also relied on structure to enact his responsibility to his students by directing them and keeping them from getting frustrated. Within the context of Eric's objectivist stance, it was the knowledge that Eric carried with him, information and experiences, which afforded him the sense of authority. He told them and they listened. Because he saw knowledge as objectively real, then the most sure and efficient way to

transfer that information was through direct instruction. Eric saw it as his responsibility to transfer the knowledge he had, and it was not reasonable to teach the historic, "wrong" models. He could use them to teach about the process of science, but only from the context of hindsight; teaching with the end in mind.

Finally, considering time constraints, Eric felt responsible to make sure that students got all of the information they needed within the time allotted for the course. He interpreted the intervention as an "insert" into the regular curriculum material. This stretched an already tight schedule. "It was not a history of science class." He saw modifying the tools designed for the intervention, adding structure, direction, and a logical story in the context of the ending, as the best way to accommodate the time constraint. Refer to Table 1 for the summary of influences on Eric's instructional decision making.

A Tale of Two Metaphors

This section presents analysis of the data through the lens of Eric's use of metaphor. Human's understanding of the world comes through our embodied awareness of it. This means we have concrete experiences, received through our senses, that we project onto abstract concepts to understand them. The use of metaphor is automatic and unconscious and structures our reality. When Eric talked about teaching, learning, and science, he did so within the context of two separate compound metaphors. I identify them as the *puzzle metaphor* and the *field trip metaphor*. They incorporate the associations and extensions (entailments) of two common primary metaphors, the *mind is a body metaphor* and the *event-structure metaphor*. Entailments are the associations or implications we link to a metaphor based on our commonplace cultural knowledge of the source of the metaphor; extensions of the metaphor (Lakoff & Johnson, 1999). For example, Lakoff and Johnson described extending the *thinking is manipulating objects*

metaphor, to get *ideas are manipulable objects*, *understanding is grasping*, *communicating is sending*, and *memory is a storehouse*. Mapping the entailments refers to the matching aspects of the source domain (*memory is a storehouse*) to aspects of the target based on Eric's words (*building* them a *memory palace*). I argue below that Eric's use of metaphor explains the teaching choices he made because their structuring afforded him certain teaching tools and limited others.

Eric's Use of the *Puzzle Metaphor*

Oftentimes, when Eric spoke of teaching or learning science, he spoke of it in terms of a puzzle (theory) whose pieces (details or facts) he would give out (teach) to students. Subsequently, students had the responsibility to receive and store (learn) the pieces and put them back together (understand). This metaphor incorporates entailments of both the *mind is a body metaphor* and the *object-event structure metaphor*, listed below.

Mapping the *puzzle metaphor*. According to Lakoff and Johnson (1999) the *mind is a body metaphor* is a very common metaphor, and is the basis for several subsystems of other common metaphors. The pertinent subsystem here is the *thinking is object manipulation metaphor*. They listed the entailments to this metaphor as (see Figure 5 for entailments and mapping):

1. Ideas are manipulable objects

2. Communicating is sending

3. The structure of an idea is the structure of an object

4. Understanding is grasping

5. Memory is a storehouse

6. Analyzing ideas is taking apart objects (p. 117)

The second primary metaphor Eric used was the *object-event structure metaphor*. According to this metaphor, events or states or purposes are considered objects. Lakoff and Johnson (1999) listed the following entailments derived from this primary metaphor (see Figure 6 for entailments and mapping):

1. Attributes of an event or purpose are possessions

2. Purposes are desired objects

3. Causation is a transfer of possessions

4. Achieving a purpose is acquiring a desired object (p. 97)

Within the context of *thinking is manipulating objects*, ideas are considered things, which maintain an existence separate from the mind, can be put together, shaved, flipped around, and even have a shape to them. Throughout the data, Eric referred to details or facts as *bits and pieces*, or *pieces of a puzzle*.

> Exceptions to patterns, *parts of the whole*, trying to figure out if the *sum of the parts* and the whole equal out. Or is there some synergy? Is there a little bit of Gestalt happening, wherein when you *put all of the pieces together*, it's a lot more dynamic than looking at all of the *pieces in isolation*. (20120620:36-40)
> where what they're doing is using the *given material* as *pieces of a bigger puzzle*, as opposed to just learning the *shape of those pieces*. (20120611b:37-38)

Eric was giving (*communication is sending*)[8] material as pieces (*ideas are manipulable objects*), and students would learn more than just the shape of those pieces (*the structure of an idea is the*

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[8] As a note of clarity for the reader, parenthetical, italicized phrases like (*communication is sending*) signifies the mapping of entailments, or extensions of the primary metaphors being described. It being italicized also designates it as a metaphor in its own rite. For instance, in the above example, the primary metaphor is *thinking is manipulating objects*, an entailment, or extension of that primary metaphor noted in the passage is *communication is sending* and that maps onto Eric's description of him *giving* pieces of information to his students.

structure of an object). It was then up to the student to put them together to make their own connections (*ideas are manipulable objects*).

> What you want to do is *give them pieces* and have them *put the pieces*
>
> *together*…instruct them in the *characteristics of these pieces* without enforcing or
>
> directing them to *put the pieces together* in a particular way. (20120809:357-368)

In the above passages, Eric emphasized giving ideas to students as pieces of a bigger puzzle. Here, Eric utilized entailments of the *object-event structure metaphor* where pieces of information are attributes, possessed by the whole puzzle. To cause his students to learn, he transferred (taught) to them these possessions, or pieces. Students acquired the pieces (learned) and connected the pieces (synthesized understanding), or put the attributes into the bigger puzzle.

> "And *we've got these different pieces* of evidence that were from different parts of
>
> the globe that were interpreted by different people throughout history, right?...All
>
> of these things exist but *there's a big picture* and *that big picture* has to do with
>
> the shapes of the continents, and once we started looking off shore; understanding
>
> how the system worked in total. Then we really saw *this picture of plate tectonics*.
>
> So you've been… *juggling all of these ideas* ... (20120712:54-74)

Eric described evidence and theory as the relationship between the "pieces" and the "bigger picture." In keeping with the metaphor, Eric saw the theory as the puzzle and the evidence for the theory as the pieces of that puzzle that students could juggle, flip and fit into place. The shape of those pieces was already made, something Eric described to the students. As is characteristic of jig-saw puzzles, the puzzle had only one correct and ready-made solution.

The puzzle metaphor is consistent with Eric's objectivist stance and teaching with the end in mind. The final picture of plate tectonics (the discovered cause) was the only correct answer.

The structure or shape of the pieces, each a discovered effect of the phenomenon, was also certain.

> people will *set up* an *array of pieces* and they will *leave them there* for you to
>
> look at and *make your own connections*, or not. *Leave them there* and then come
>
> back and say, "Well, we've wandered around all of these different things and *they*
>
> *are all connected*, we know *they are connected*. (20120611:306-310)

In Eric's view, the pieces of the puzzle were already known and they naturally all fit together. It was only a matter for students to make the right connections. This relieved the students of the responsibility for developing the ideas on their own. Just like an ordinary jig-saw puzzle, the big picture on the box gives the framework, or the final answer. It was ready-made science.

Eric rarely talked about taking ideas apart. He often referred to students fitting pieces together to make a coherent whole; synthesizing plate tectonics from its component parts, facts, or details. Synthesis is the opposite of analysis and therefore *synthesizing is putting together* maps very well with the metaphor.

The significance of the *puzzle metaphor*. This metaphor equated scientific theory to a large puzzle. The facts and subsidiary concepts that made up the theory were the puzzle pieces, and understanding the theory was putting the puzzle together. The experiential basis for this metaphor may very well have come from Alfred Wegener's realization of the "jigsaw puzzle fit" of the continents leading him to propose continental drift as an explanation for the origin of continents and ocean basins (Wegener, 1924). Eric was a professor of plate tectonics. It may be that Eric's experiences in the field of plate tectonics, with continents "fitting together" to form a supercontinent of Pangaea, helped to ground his understanding of learning. Science is a process for solving puzzles.

Figure 5. Example of coding for the *puzzle metaphor*, onto the *thinking is manipulating objects metaphor*. One entailment, *thinking is manipulating objects*, appears in the central light blue box. Surrounding light blue boxes map further entailments of the metaphor. Orange boxes are transcript passages concerning learning; pink, teaching; and green, science. According to this metaphor, Eric saw a puzzle (theory), and pieces of the puzzle (facts), that could be stored, flipped around (considered), broken down (simplified) and put together (learning).
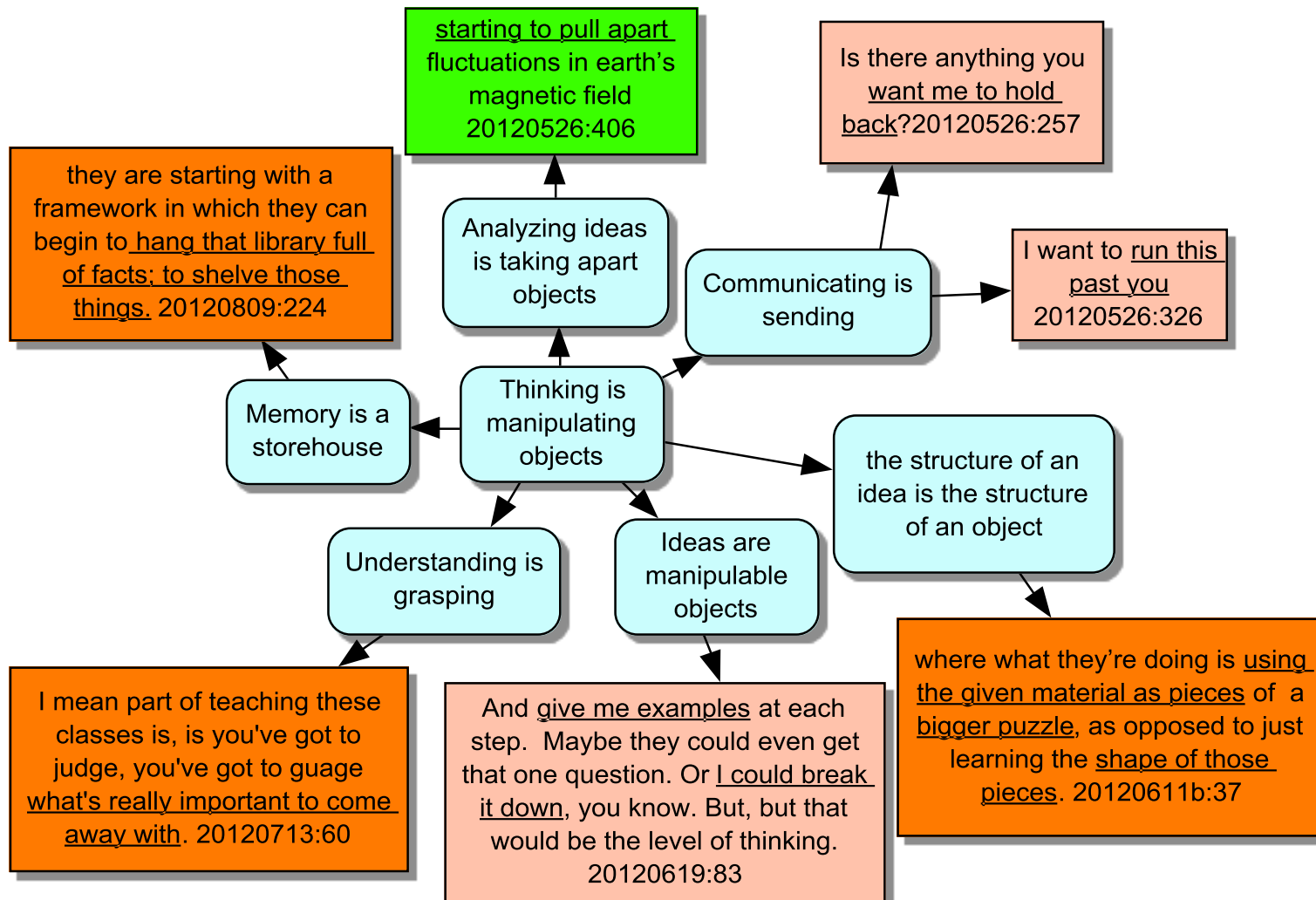
Figure 6. Example of coding for the *puzzle metaphor*, onto the *object event-structure metaphor*. Further entailments of the *object event structure metaphor* are in light blue. Light pink boxes are transcript passages concerning teaching; orange, learning; yellow, the textbook; and dark pink, students. According to this metaphor, Eric saw the pieces (facts) as constituents of the puzzle (theory) that could be given (taught) and received (learned)

Exceptions to patterns, parts of the whole, trying to figure out if the sum of the parts and the whole equal out. Or is there some synergy? Is there a little bit of Gestalt happening, wherein when you put all of the pieces together, it's a lot more dynamic than looking at all of the pieces in isolation. Umm, you know, ahh, ahh, recognizing that in some places you see particular patterns repeatedly that distinguishes those places as unique representations of a particular type of thing going on. 20120620:36

I think they're starting to really, hopefully, you know, get that a lot of this stuff is really simple 20120618:61

But I just don't think they have enough experience. 20120614b:198

Purposes are desired objects

I tried a few times to get them to talk about the models. 20120614b:197

- I need for them to understand particular basic things that are in the text 20120611b:34

Attributes are possessions

Object event structure metaphor (Lakoff & Johnson, 1999)

Achieving a purpose is acquiring a desired object

So, pumping their heads full of knowledge or stuffing their heads full of facts in a disconnected way is not necessarily a- is not necessarily effective. 20120614a:134

Causation is transfer of possessions

and I am supposed to be giving them the information that they then give back to me. 20120611:42

describe how plate tectonics both incorporates, and integrates, and *synthesizes all of these pieces to make a coherent whole…*describe the *pieces of data*, like yesterday's lecture, describe the important *pieces of data* that we use to test and support plate tectonics. What is important about these *disparate pieces of data*? (20120619:167-173)

Eric taught that scientists synthesized the theory through the 1960s and 70s. Just as with the layered earth story, students should be able to simply and logically put the pieces together. The difference is that scientists had many pieces and not all of them fit, and some of the pieces may have needed shaping to get them to fit. What Eric taught was only relevant data; the pieces that came directly from the puzzle. He taught with the end in mind; the shape of the pieces, not how to put them together.

Due to its success at explaining geological observations, globally, plate tectonics has become the context within which geological investigations are conducted. Therefore Eric saw this theory as the one correct way to put those pieces together. It was his responsibility to impart connection making skills to the students as well. The students need only receive the pieces and put them together in a straightforward and logical manner, through knowing the shape, and flipping and juggling the pieces around until they fit. Students also stored the pieces on the shelves of their *library of facts* or within their *memory palace*. The implications of the metaphor are that the pieces were ready-made in shape and quantity, as constituents of the ready-made big picture, or puzzle. There was no real need for student creativity in the learning process.

Eric's Use of the *Fieldtrip Metaphor*

The *field trip metaphor* is a compound of the *thinking is moving* subgroup of the *mind is a body metaphor* and the *location event-structure metaphor.* According to the mapping of these

metaphors, knowledge was the terrain that Eric led students across. Learning was discerned as forward progress along the path to a final destination; marked by the event of understanding the theory of plate tectonics. There was some rough and dense terrain (readings). There were also some impediments or barriers (vocabulary) to forward progress. Eric saw it as his responsibility to cover the ground (content) along the path (thinking), guide (teach) them so they would not get lost (misunderstand), expose them to background (foundational) material when necessary, and prevent them from flailing in a wilderness through which they would travel (be learning).

Mapping the *fieldtrip metaphor*. Lakoff and Johnson (1999) pointed out that we have an abundance of knowledge about motion in space, simply because we have a great deal of experience moving ourselves or other objects though space. These experiences, then, become the knowledge upon which we draw to make sense of events (in this case) that take place in our lives. Looking at the entailments of the *location-event structure metaphor* reveals that (see Figure 7):

1. Long-term purposeful activities are journeys

2. Actions are self-propelled motions

3. Difficulties are impediments to motion

4. Causation is forced movement (from one location to another)

5. Changes are movements (into or out of bounded regions) (p. 88)

With regard to the *mind is a body metaphor*, Eric's discourse contained many references to its sub-group metaphor, the *thinking is moving metaphor*. The entailments are (see Figure 8):

1. Rational thought is motion that is direct, deliberate, step-by-step, and in accordance with the force of reason

2. Communicating is guiding

3. Rethinking is going over a path again

4. A line of thought is a path

5. Ideas are locations and thinking about something is moving in an area around that

    something (Lakoff & Johnson, 1999, p. 115)

Fundamental to the *fieldtrip metaphor* is the idea of traveling from one point to another;

where thinking is considered to be moving along a path and learning is a purposeful journey to a

destination of understanding. Lakoff and Johnson (1999) outlined the important aspects of taking

a journey. For instance, there needs to be a plan (syllabus), or a route (series of lessons) to get to

the destination (understanding), sometimes there are obstacles (learning challenges) to traveling

that must be anticipated, there are supplies (text, models, etc.) that need to be brought and an

itinerary (course schedule) that should be made indicating where the journey leads (content),

what stops (lessons, units) there are and how long will be spent at each stop. Eric often spoke in

terms of the journey.

> If we could sort of *lead up to* Thursday, umm, and, *get a lot of stuff-* and this class
>
> is actually front loaded in terms of plate tectonics. *We are starting* with it. So, if
>
> you could *gear up and get ready to roll*, and work with [Paul] in terms of what he
>
> wants to do for lab and maybe even, you know, *roll what you are doing into* what
>
> he *is going* to do for lab...that would be really good if we could *do it that way*.
>
> And Uhh, the thing that I would like to do with this is to try and *streamline what*
>
> *we did* last time *around* so that it fits into that one week maybe plus or minus a
>
> day. (20120705:123-133)

Eric set a departure time (Thursday) and location (plate tectonics) for a journey along a path

(thinking about plate tectonics) that would lead to the destination (the event of having learned

about plate tectonics). He was concerned that we get "a lot of stuff" and "gear up" (get texts and equipment, videos, etc.) for the journey. Although he wanted us to "streamline" what we did the last time we took this journey, so he could go quicker, he still wanted to go the same general way. Eric also would be "*leading them through that*" (20120620:43), or "*guiding them towards* this idea of *taking* good data…" (20120705:300).

> I feel like they potentially get more out of an intro class that teaches them and
> *guides them towards a way* of thinking… And if they are interested students that,
> and *come back to* take more classes…least *they are starting* with a framework in
> which *they can begin*… (20120809:214-225)

In his view, Eric guided (communicated with, or taught) the students along a path (thinking). This path was helpful to students, even those not following any further. Going this way would help them to navigate the news and other decisions in life. However, if the students were interested, they could come back to the group and continue on the journey.

> Eric shared the role of guide with the textbook as well. It aided him.
> It also *is a crutch for me*…I *can get to* and use the resources available in the text
> to, umm, *drive a discussion*… I feel that students without a book *will be a little bit*
> *lost*…the text book *in some ways* becomes *a crutch for both the students and the*
> *professor*... (20120809:441-458)

He perceived he and the students used the textbook as a crutch along the path. The text could help drive discussion and lead students to a certain point without getting them lost. This is not inconsistent with Eric's earlier assertion that the text is ballast or a security blanket (or security sleeping bag, maybe) for the students; something that they have to carry and will help them get to their destination.

Figure 7. Example of coding for the *field trip metaphor*, onto the *location event-structure metaphor*. Further entailments of the *location event-structure metaphor* are in light blue. Light pink boxes are passages concerning teaching; orange, learning; green, science; and dark pink, students. According to this metaphor, Eric lead (teaching) a journey through a terrain (content material), where student followed (learning) making multiple stops (lessons), avoiding impediments (difficult concepts) to reach the ultimate destination (understanding of plate tectonics)

And leading them through that- and I think they got some pieces. I mean, he was, he was right on. He was like, "Hey, if it's not expanding, then doesn't that stuff that gets created in one place have to be destroyed?" Yes. Absolutely. Absolutely. That's right. You know and getting them to make that jump, you know, it's a conceptual jump. And then they can go back and start filling in some of the pieces. Because there's lots of little if-then statements that get you from A to Z. And yes, going from A to Z is correct. It's like Wegener. Right? He really did get it. But he didn't get all of the if-then statements that got him from that starting point to the finishing point.20120620:43

And then, and then, and that's the thing they start seeing; the contortion that people put themselves through defending their model. And that's when you know when things are on the down hill slide. 20120614b:189

Actions are self-propelled movements

vocabulary is such a barrier for people who might intuitively or, or, or maybe not intuitively but actually be intellectually get what is going on 20120611:b124

Long-term, purposeful activities are journeys

Location Event-Structure Metaphor - Events are locations (L&J, 1999, p. 88)

Difficulties are impediments to motion

to order or structure that allowed me the freedom to learn in my own way and my own pace within a structure that kept me on track to get me through the material. 20120611b:241

Changes are movements (into or out of bounded regions)

States are locations (interiors of bounded regions)

Causation is forced movement (from one location to another)

It's also interesting flipping back and forth between lecture, discussion and play 20120611b:100

Umm. Or don't have the words, so there's that. Umm, part of it is, part of it is that getting to the point of being able to discuss that material requires, requires reading it. 20120614b:29

And see if I can pull them into hot spots, satellites, radio telescopes 20120713:13

 Figure 8. Example of coding for the *field trip metaphor*, onto the *thinking is moving metaphor*. Further entailments of the *mind as a body metaphor-thinking is moving* are in light blue. Light pink boxes are passages concerning teaching; orange, learning; bright blue, the intervention. According to this metaphor, Eric guided (taught) students to various locations (concepts), along a particular way (mode of thinking about the content) to a final destination (theory of plate tectonics).
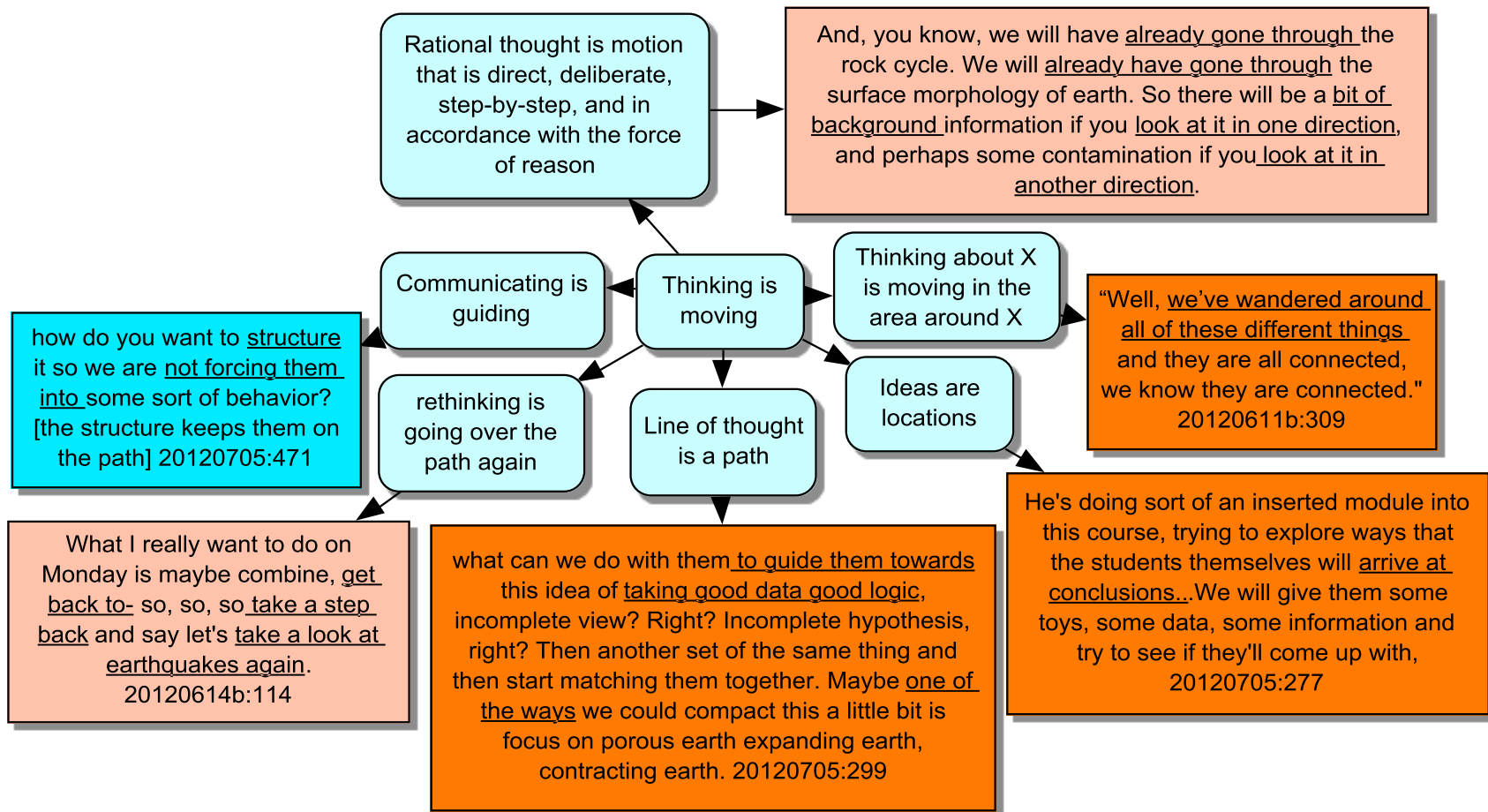
Of course, with all journeys, there is the possibility of obstructions. Students must devise a way to overcome impediments to further progress. Eric saw two different types of structure along the path of learning; one blocking and one guiding.

> vocabulary is *such a barrier* for people who might intuitively or, or, or maybe not intuitively but actually be intellectually get what is going on (20120611:b124-126)
>
> a *structure that allowed me the freedom* to learn *in my own way* and *my own pace* within a *structure that kept me on track* to *get me through* the material.
>
> (20120611b:240-243)

In Eric's view, the geologists' vocabulary posed a formidable barrier to the students. Without a working knowledge of the language of geologists, even if there was conceptual understanding, this impediment was apt to prevent students from making further progress. However, Eric did also talk about structures that more or less occurred parallel to the path. This structure was emplaced by his teachers and allowed him the freedom to get through the material in his own way and his own pace. Basically, Eric perceived that being within this structure kept him on track. This idea was important as he discerned his role as guide. He would create the same structures for his students to keep them on track and free from flailing which self-direction would inevitable lead to.

The significance of the *field trip metaphor*. As with the *puzzle metaphor*, determining the implications of the *fieldtrip metaphor* is important in understanding the motivations in Eric's instructional decision making. Eric considered his role as the guide to his students on their way (learning) through some terrain (content material). There may be some barriers (vocabulary, for instance) that they would somehow have to jump (have faith) to some conceptual understanding. They might have to bring with them supplies or assistance walking (textbook, etc.), but with

careful planning and the appropriate stops, guidelines (structure), and benchmarks (facts) along

the way (to keep them from getting lost), they could get from A to Z (logical thinking) and reach

their destination (understanding).

> Well, because they want to have *benchmarks*. You know? They want to have
>
> proof of x, y, or z, right? (20120619:70-71)
>
> And *leading them through that-* … You know and getting them to *make that jump*,
>
> you know, it's a conceptual *jump*. And then *they can go back* and start filling in
>
> some of the pieces. Because there's lots of little if-then statements that *get you*
>
> *from A to Z*. And yes, *going from A to Z is correct*. It's like Wegener. Right? He
>
> really did get it. But he didn't get all of the if-then statements that *got him from*
>
> *that starting point to the finishing point*. (20120620:43-54)

 Here, Eric described the importance of known locations along the way of the journey. These

certain facts would serve as benchmarks (reassurance they are not lost) for students. They may

even have to make jumps (acceptance) to keep progressing. Eventually, students will have made

all of the stops from A-Z and reached their destination (understanding), just like with Wegener,

only he may not have stopped at all of the stops along the way.

Eric's use of the *fieldtrip metaphor* has its experiential basis in one of the major teaching

tools in geology; the fieldtrip. The field trip uses maps, is very scheduled, has many stops along

the way and a leader or leaders. The leader's responsibility is to progress from one location to

the next, to show and interpret the important features at each stop, and then to move on,

advancing the story from A to Z, while also not letting anyone get lost. The implications of the

field trip are that stops, the path and the destination are already well blazed (ready-made) and

known to the fieldtrip leader. In this way, the students' role is simply to follow and listen to the

leader, and hopefully pick up some stuff along the way. They are not encouraged to wander off the path, or really be self-directed in any way. This could slow or even halt progress (see below). If they continue in a straightforward manner, from stop to stop, eventually, at the end of the trip they will have an understanding of the ground (content material) they covered.

The Roles of Authority and Responsibility.

The roles of authority and responsibility within these metaphors parallel what has already been described above. Little is added to that argument here. This section describes how Eric expressed his authority and responsibility to his students within the gestalts of the two different metaphors.

As the expert in the class, Eric saw himself as the holder of the puzzle pieces. He saw the students in need of the pieces so they could put together the puzzle for themselves; "because I'm the lecturer and I am supposed to be *giving them* the information that they then *give back to me*" (20120611b:42-44). This gave Eric a sense of authority in class.

As Eric saw it, students perceived themselves as subordinate to him, making them hesitant to participate in discussions because they were afraid of being wrong in front of him. He also perceived that they expected to receive the knowledge he and the textbook had to give. He perceived students' attitude being, "you are the teacher and you will teach me" and the textbook is a security blanket, grounding course material in the truth.

The job of field trip leader came with a sense of responsibility. Eric said that he was "always *looking for better ways* to engage students" (201200611b:348-349). Eric also perceived his responsibility to cover as much territory (content material) as possible, get through the journey on time, and not let anyone get lost. This meant not allowing much self-direction for

students. But Eric also perceived that students wanted boundaries. Just as they wanted him to

give pieces of information, they looked to him to be a responsible leader and keep them on track.

> When we set up the experiment *in a particular way*, they feel that *that is the way*
> the experiment should be…There is a framework and *a guideline. There's a track*
> and everything *has to be this way*...And I think thinking *outside of those*
> *boundaries* is something that they have not been doing…if you *give them that*
> *push*, *are they going* to then- *are they going* to… And the whole set up of lecture
> and teacher-student is an interesting one in terms of *setting the guidelines for* how
> the learning happens…I want them to *get to the point* [free but on track]...That's a
> very hard *point to get to*. (20120611b:10-41)

Eric thought his students perceived that the structure of the class was purposeful, and they were

not allowed to break the rules, or wander off that particular path. They had to follow the

guidelines. On the one hand, Eric sensed a need for some structure for his students; that they

needed background and experience. He thought that self-direction would lead to flailing and

become an impediment. Yet, he said that he did want to get his students to a point where they

could let go of the structure because the ready-made path would be so worn and obvious, like

putting the puzzle pieces together in the one logical way. He asserted that getting to that point

was difficult.

CHAPTER 6: DISCUSSION AND CONCLUSIONS

Understanding the ways that teachers transform the core ideas of curriculum

materials into practice is important, given how frequently curriculum materials

are used by reformers and policy-makers as tools to influence instruction. (Brown,

2009)

In this chapter, I place the findings within the larger framework of curriculum design and

implementation, and faculty professional development. The first section recounts Eric's $PC_{xt}K$

and its relationship to the metaphors he expressed when talking about teaching, learning and

science. It also explains how these metaphors afforded and constrained certain tools for teaching.

I then discuss the advantages to analyzing the data collected from Eric for metaphors over other

current tools for analysis. Section two explores the role of objectivism and its influence on

understanding teaching and learning. The final section discusses the implications for the design

and implementation of innovative curricula as well as faculty professional development.

The Alignment of Eric's $PC_{xt}K$ With the Metaphors He Taught By

This section summarizes Eric's $PC_{xt}K$ and shows its alignment with his metaphorical

teaching structures. The alignment not only explains why Eric made certain instructional

decisions, but also substantiates the identification of metaphors as a promising methodology for

explaining and even predicting instructional decision making.

The Themes of Eric's $PC_{xt}K$

Based on the data, Eric both demonstrated and described his struggle with incorporating

less structured activities in class. He referred to them as free-form, self-directed, and play.

Though he did acknowledge that these types of activities were effective at engaging students, he

was more worried about them getting the basic stuff they need. Accordingly, he did not use many

of the intervention activities that called for small group or whole class discussion. The ones he

did use, he either led, or structured in such a way as to direct students to the outcome he expected.

Eric maintained an objectivist epistemological stance with regard to scientific knowledge.

In accordance with this, the knowledge he had about phenomena was what was really going on,

and historic models were wrong. Eric did discuss these models, but he did so by contrasting them

to the theory of plate tectonics. Students would not confuse "how we talk about it" with the

"incomplete views." He had this information and it was his job to dispense it. This stance also

determined the most effective teaching strategies to be telling and reading.

In the manner of contrasting historic models with the current accepted theory, Eric

always taught with the end in mind. All of the information he gave to students was couched in

the understanding of plate tectonics. According to this style of teaching, Eric would say, "this is

why we observe this the way we do," as opposed to "what do these observations tell us about

how the earth works?" as the intervention called for. It was the difference between presenting

students with ready-made science, instead of them experiencing science in the making.

Time was another influential constraint for Eric. He already considered regular college

semester courses to be short compared to the amount of time he needed to cover course content.

The brevity of the summer courses and his perception of having to fit the intervention in

exacerbated Eric's "time crunch." The intervention called for a lot of student autonomy in

building their models. Eric asserted that the extra time spent might be beneficial if the class were

longer, or if it were a "philosophy of science" course.

Eric granted authority to the textbook, arranging his syllabus in deference to its table of

contents. It held a lot of information and the students needed it to ground the course material in

reality. He saw student success as dependent on their inherent capacity to receive his knowledge

and whether they had enough background information to fully understand the course content.

The themes are coherent with those described by Banilower, and his colleagues (2013), Barnett

and Hodson (2001), Höttecke and Silva (2011), the NRC (2006), Orion and Ault (2007) and

Stein, and her colleagues (2009), adding to the reliability of these findings.

Eric's PC$_{xt}$K and the Two Metaphors

The analysis of Eric's use of metaphor both substantiates and extends the PC$_{xt}$K themes.

Eric referred to teaching, learning, and knowledge in terms of the *puzzle metaphor* and the *field*

trip metaphor. It is reasonable to associate the experiential bases of these two metaphors with the

"jig-saw puzzle" reference commonly associated with Wegener's continental drift theory, and

the relative significance of fieldtrips to the teaching of geology. Eric would have experienced

both of these throughout his trajectory from student to geologist and professor. Lakoff and

Johnson (1980) asserted that the metaphors we use are very important because, unlike explicit

beliefs, metaphors are lived unconsciously, therefore they are not noticed and escape critical

assessment.

Mapping the two metaphors. According to the *puzzle metaphor*, a theory was the big

picture or whole puzzle. The facts that made up the theory were the constituent pieces to that

puzzle. Eric said the puzzle pieces could be put together if they were properly positioned, flipped,

or juggled around. Putting the pieces together to make a coherent whole was simple and logical,

and an indication of understanding the whole theory. When mapping out the *field trip metaphor*,

the theory was the ground over which the field trip navigated. Facts were designated stops or

benchmarks along the way. Learning was forward progress along a path, covering ground.

Challenges to that learning were barriers to forward progress. Understanding of the material was

equated to reaching the final destination.

The two metaphors paralleled each other in a number of ways. First, both metaphors made allowance for the theory/fact relationship. Scientific facts are attributes of a particular theory and Eric often referred to the pieces as constituents of the puzzle. The attributes of theory in the *fieldtrip metaphor* were parts of the terrain; locations along the path. They might be benchmarks that students looked for, or locations they needed to be pushed to cross, or pulled into. They might have to make a conceptual jump right over it. Some were even barriers if they were hard to understand.

Second, in both metaphors, Eric perceived himself in a position of authority. For the *puzzle metaphor*, Eric, and the textbook, possessed the big picture, or puzzle, and could break it down into smaller pieces of knowledge. He saw his role as giving these bits and pieces of knowledge to the students, and for the students to put them back together. According to Eric, this should be a relatively straight forward task because, as with puzzles when they are received, the shapes of the pieces and the puzzle are already made. All the students have to do is think logically and fit the pieces together. For the *field trip metaphor*, it was the path that was already made. Eric led the trip and designated and interpreted the stops. However, he also had the responsibility to get the student through the course on time. To do so he "might have to be a bit Nazi about rolling through lecture." He had to push them to make conceptual leaps, and pull them into different topics. He had to structure the way with guidelines and benchmarks to keep students on track and to not let them get lost. He also had to keep them from flailing because the course was massively accelerated, and flailing would slow them down.

Third, Eric wanted to give the pieces to the students and describe the shape of those pieces, yet he did not want to force students into putting the puzzle together in a certain way. He would leave that up to them. Eric also expressed the desire to have students get to a point where

they could be self-directed along the path. But again, like the pieces and the puzzle, the path was already made, and the stops were already planned and well interpreted. Students should understand the logic of following a path that has already been blazed.

The implication for both of these cases reflects an objectivist epistemology. That is, facts should speak for themselves. There is no need for negotiation, or interpretation of meaning with, or by students. The shape of the puzzle pieces was given, the trail blazed. Learning should be simple, strictly a matter of common sense and logic. Herein lies the strength of this type of analysis. I did not ask Eric for his explicit understandings of teaching, learning, students, knowledge, or science. I gathered data from his teaching and discussions that focused on *how* he was teaching, how his students were learning, and how science was being done. By looking at the language Eric used during these discussions, I discerned patterns of how Eric structured his reality with respect to those topics. Those structures were consistent and paralleled his actions throughout the entirety of the investigation period. By contrast, much of the teacher beliefs literature reports on researchers looking for answers to direct questions about beliefs. Kahneman (2011) described how, in general, people easily develop beliefs about the decisions they made by looking for a rationale for their behaviors, *post hoc*, making up a reasonable response, and then believing what they just made up. One can surmise this leading to inconsistencies and contradictions in among different sets of an individual's beliefs. Such seeming inconsistencies are readily observable in the results from the section on teacher beliefs in Chapter 2 where researchers found inconsistencies and contradictions with participants' reported beliefs and discordance in relating those beliefs to their practices.

Whether Eric's language primed his actions or his actions primed his language is not so important here. Either way, by determining these two metaphors Eric taught by, from the

patterns in the data, I have an understanding of how Eric structured his reality. I can also develop

implications through the mapping process and make predictions based on those implications.

From the structure of Eric's reality, I can understand why Eric decided to use certain tools and

why he used them the way he did. I can do this because the metaphors afforded certain options

and constrained others.

What the metaphors afforded. The metaphors Eric taught by made some instructional

tools at his disposal more reasonable than others. The *puzzle* and the *fieldtrip metaphors* allowed

Eric a position of power, as holder of the pieces of knowledge or field trip leader. In either case,

he had the authority and responsibility to give the pieces of information to them, or lead and

interpret stops along the path. His role favored direct instruction. Students received or followed.

As such, the tools most appropriate to Eric were lecture and what he identified as discussion (in

actuality, lecture without assistance of the PowerPoint). Of the 14 class periods of intervention

over the two iterations, Eric lectured during everyone. Most lectures lasted close to the entire

period except during those classes where the four approximately hour-long activities took place.

Lectures were 30-40 minutes in these instances.

One direct instruction tool was teaching with the end in mind. At one point in class, Eric

said, "I'm probably stepping on something Glenn wanted to do, but…" and went on to discuss

the strengths of plate tectonics compared to other historical models. This doling out of "ready-

made science" was in sharp contrast with the experiencing "science in the making" goals of the

intervention, to look at different data and competing models, asking all the while, "What does

this tell us about how the earth works?"

Because Eric already had the big picture, it was easy for him to see the pieces, namely

earthquakes, volcanoes, mountain ranges, and ocean basins, as *results* of plate tectonics, as

opposed to *evidence* supporting a possible explanation. For Eric, developing the theory as a

coherent whole resulted from direct and logical thought and exploration by scientists, or making

the right connections by students. His teaching was "cleansed" of the errors of thought, dead end

investigations, and incomplete data of the past (Allchin, 2002). Only the observations that led to

the theory need be taught. Taking this stance precluded such historical models like Aristotle's

porous earth or Dana's contracting earth as wrong models created from incomplete or

misinterpreted data. Eric considered teaching about them as malpractice.

Allchin (2003) described this way of teaching the history of science as a "rational

reconstruction." It is this manner of teaching that misleads students' understandings of NoS by

picking out only the data that answers the pertinent question and presenting it to students who

already know and therefore only have to verify the answer. Instead, Allchin argued to give

examples of science in the making with its uncertainties, to respect the historical context,

complexities and controversies, and to explain errors instead of purging the history of them.

Reading was another tool Eric chose often. Most readings were from the textbook. This

was an important tool for Eric. Even after he said he would not assign readings from the book in

deference to my concern that the readings were written with the end in mind, eventually he did.

He also used the eye-witness accounts of the 1906 San Francisco earthquake, excerpts from H. F.

Reid's report concerning elastic rebound theory and the summaries of the historic models of

earth dynamics. In contrast to a constructivist epistemology where words are interpreted and

quite possibly not as the speaker intended, an objectivist epistemology considers meanings to be

in the words. For Eric, this meant that students could get just as much from reading as they could

from him telling them. The readings had a certain authority of knowledge. Though Eric

considered many of the intervention's readings to contain a "personal entry," "wrong hypotheses,"

or to be "too dense," he attempted to mitigate these drawbacks by using summaries of historical

readings and structuring discussions around the major points he wanted them to get from the

reading. Even so, Eric did not assign any of the intervention's readings later in the

implementation. The intervention called for small group student discussions to accompany each

reading or set of readings. Discussions between and among students in response to readings

never happened.

Eric did take up two of the inquiry activities called for by the intervention, the earthquake

machine and the seafloor data activity. The earthquake machine (Figure 2) was new to Eric, but

an activity very similar to the seafloor activity was already incorporated with the laboratory

structure of the introductory geology courses. For the first iteration, he implemented both

without any written directions or worksheets. There were no written questions to answer at the

end. Students performed these activities with varying levels of engagement. However, every

student present did participate. Eric spoke a number of times about his struggle implementing

such free-form activities. Though he appreciated the engagement the activities garnered, he was

uncomfortable that students could derive the appropriate knowledge they needed. As a result,

Eric asked that some instructions and some questions be added to the activities to help direct

students. Eric could feel more comfortable that students were getting what they need by

themselves. Structure also helped to streamline the activities so they would take less time. Eric

utilized the laboratory activities early on in the intervention, leaving the end for lecture-based

instruction.

What the metaphors constrained. In considering both the *puzzle* and *fieldtrip*

metaphors, there are aspects of the target (learning) that do not get mapped by the source

domains (puzzle and fieldtrip). These "non mapped" aspects of the target are essentially hidden

by the gestalts of the metaphors. They are the tools Eric overlooked, because according to the

way he perceived teaching and learning, they were either not as useful, or not considered tools.

The metaphor structured gestalts hid the amount of work that must take place in actual and

meaningful communication (Reddy, 1979), the subjectivity of the meaning made, and the role of

student-student interaction as an instructional tool for meaning making.

During communication, the brain must filter, decode, interpret, and categorize the signs

and signals (Kahneman, 2011). It does this unconsciously and automatically. To learn a novel

concept, the learner must utilize new experiences, if available, and then fix them to already

existing experiences or portions of previous experiences in the mind. Learning engages processes

like thought experimentation, analogies and visualization (Carey, 2010; Clement, 2010;

Nersessian, 2008). This is much more work than the myth of objectivity (Lakoff & Johnson,

1980) implies.

The prescribed pieces and a blazed trail of Eric's ready-made science hid the subjectivity

of the students' final understanding. Since novel concepts are built on the learner's past

experiences, the new knowledge will not be identical to anyone else's, or the source's. Finally,

the puzzle and fieldtrip gestalts hid the importance of such instructional tools as collaborative

work among students and between students and teacher. Students trying to negotiate meaning

together might take an alternative path. Eric would have to anticipate such "forks in the road"

and be there to mark the appropriate direction (Stein, et al, 2009). Belief that meaning was right

there, in the words, meant there was no need for interpretation by students. There was no need

for activities such as collaboration, mutual construction of understanding, negotiation of meaning.

There was no worry of them taking a different path. Meaning already existed and was universal.

Eric rarely had students work with each other. They never had to rely on each other, or even talk

to each other in class. Students rarely answered questions posed by Eric. They focused their

attention on the holder of the pieces, or the leader of the field trip and copied his words or

writings carefully. They picked up the facts as he dropped them. There was a little collaboration

during the inquiry activities, but that was only a small percentage of total class time.

The Role of Objectivism

Considering the pervasiveness of traditional style teaching (in both time and space), it is

easy to understand that objectivism forms the foundation of how many think learning happens

(Bartholomew, et al., 2004; Sfard, 1998). Prior to the days of cognitive science, teaching

practices arose out of utility, and the ones that appeared to be most effective were repeated, the

less effective were dropped. From this process, arose a "folk theory of mind" (Bereiter, 2002). A

folk theory is a set of practices that work but with no explanation for why they should. Bereiter

went on to point out that the folk theory at work in education is the *mind as container* theory.

This metaphor creates meaning that the mind is a container into which we can put ideas. Sfard

(1998) identified this understanding about learning as the *acquisition metaphor of learning*. She

said the way we normally talk about education, "makes us think about the human mind as a

container to be filled with certain materials and about the learner as becoming an owner of these

materials" (Sfard, 1998, p. 4). This matches very closely with Eric's descriptions of "stuffing

students full" of information, "building them a memory palace," and giving them "bits and

pieces" of information.

The use of this metaphor makes a great deal of sense. Students have learned by

experiencing instruction that emphasizes acquisition of knowledge. The system identifies these

students as "good students," because they happen to be successful. The question is, are they

successful because they are good students or does the system identify them as good students

because they happen to be successful with this mode of teaching? Also, our language is rife with metaphors that represent ideas as things being transferred from person to person via communication (Grady, 1989; Reddy, 1979). Lakoff and Johnson (1980) pointed out that the experiential basis of this metaphor comes from our receiving information through our senses, which is then translated into meaning. Books with information come into our possession, sounds from a lecturer travel to us. We are not usually aware of the sense making process. Therefore it seems as if we received the meaning rather than the signals to create the meaning.

Giere (1988) demonstrated how objectivism is common in scientific research. He described a type of objectivism (constructive realism) in his study of particle physicists in a proton accelerator lab. In the lab, physicists working on creating beams of protons for experimentation were speaking of and manipulating protons as if they were real entities that had the physical properties ascribed to them by theory. Having never directly observed a proton, the concept is purely theoretical. However, that theory has been so tested, and is so predictable that the physicists in the laboratory took for granted that it is a real object that they can now use it as a tool for research on other subatomic particles, as opposed to an object of study itself. Giere said that it is important to understand that scientific knowledge is created, but it is also important to not take for granted the importance of considering previous results as "real" in order to further investigation.

Being a scientist and studying such a well-supported theory as plate tectonics, it was easy to understand Eric's objectivist stance while teaching. Like the protons in Giere's (1988) study, plate tectonics is a construction from many areas of science. The main theory is so well established that it forms the context in which geological investigations are set. It is used as a tool

for prediction, for determining what should be found in a location that has a particular tectonic setting.

> we are able to predict with ever finer detail, OK, well, if what we have is flux
>
> melting of the mantle which has been contaminated by the sediments in a
>
> subduction zone, well then the earliest stuff should be the hottest melting least
>
> contaminated and the youngest stuff should be the coolest melting and most
>
> contaminated. And then we go and look in these Andean arcs and low and behold
>
> we find basaltic andesites at the bottom of the pile and rhyolites and dacites at the
>
> top of the pile. (20120809:258-265)

For Eric it was perfectly reasonable to teach plate tectonics as the cause as opposed to an explanation; ready-made science, as opposed to science in the making. In our initial conversations about the intervention, I expressed my desire to record students building their own model to explain data given them. Eric heartily agreed. He thought it was a great idea to have students "put the pieces together" for themselves. We were *saying* the same thing, but each of us was speaking in terms of a different gestalt. "Putting it together by themselves" *meant* something very different to each one of us.

Implications for Curricular Design and Professional Development

As this investigation unfolded, the parallels to Reddy's (1979) "tool makers paradigm" (Chapter 2) became more and more apparent. To recall, Reddy described a scenario where people lived in a compound that looked much like a wagon wheel in map view (Figure 1). Each pie shaped piece of property was bounded by walls that were the "spokes" of the wheel and the connecting arc of the circumference. The terrain of each property was generally the same but with some differences. Communication between properties could only take place through the

transfer of symbols, written on paper, via a communication device at the hub of the compound; symbols that, once received, needed to be interpreted and utilized to make a tool. The construction of the tool and its subsequent use was based on the recipient's past experiences and the context (terrain) within which he was living. In Reddy's story, the person in a well forested terrain made a multi-pronged rake of wood for raking the leaves that fell every season. The neighbor, who lived in a very rocky terrain, could not understand what the tool was for, but was able to fashion something similar and useful for moving the stones from his fields. He modified the plans based on the materials available and the context of the tool's use.

Applying the analogy, I was one of the residents of the compound. I was also under the spell of Reddy's (1979) "evil magician." I had developed plans for the tools for teaching earth dynamics and the nature of science, and I was going to hand them over to Eric. The spell kicked in when I thought that I had given Eric the actual tools and not the plans, or symbols, for the tools that Eric had to use his past experiences and the materials of his terrain (the terrain revealed through his use of metaphor), his $PC_{xt}K$, to construct his own tools. What I neglected to take into account was that Eric had different $PC_{xt}K$ from what I was expecting – my experiences and my terrain. By not considering the impact of Eric's interpretation based on his $PC_{xt}K$, it was easy for me to think that he would be using the same tools that I had constructed. I was presenting "ready-made teaching" and not fostering "teaching in the making." As mentioned above, though we even used much the same language to describe our individual goals, we maintained two different perspectives of the intervention.

My realization of our difference in perspectives prompted a closer look at the terrain in which Eric was operating as a way to understand his choice, construction, and use of the tools. This dissertation is an attempt to scale the wall and take a peek at Eric's terrain to understand his

PC$_{xt}$K. Consequently, in the process of making innovative tools for him, they maintain a familiarity and usability to him, but also encourage a shift toward such effective practices as presented by Bartholomew and her colleagues (2004). This will enhance the overall product of his work, namely, student learning. It is what Brown (2009) called for in the quotation opening this chapter.

With an understanding of the metaphors that guided Eric's practice, what, as a curriculum designer, could I have done to make the tools of the intervention more usable for him as well as develop him further along the directions of more student-centered practices? The contributions from this study come as other curriculum designers realize they must build curricula that takes into account "teaching in the making;" it allows for the negotiation between the intended use of instructional tools and the instructor's metaphorically structured reality. Discerning the metaphorical structuring of an instructor's PC$_{xt}$K illuminates the themes that are influential in her/his instructional decision making. With this information curriculum designers or teacher educators can map new entailments of the structuring metaphor, or an all new metaphor, onto the instructor's PC$_{xt}$K, that will highlight the aspects of teaching that are more student-centered. This would require the explicit and reflective use of the new metaphor by the instructor. Successful transition to this new metaphor by the teacher is also contingent on support of the environment and colleagues comprising the local culture of teaching. One place to start changing this culture is by emphasizing teacher development for GTAs who can then set the tenor for the culture in the future. I address these points in the following section.

Knowing What I Know Now…

From the initial meetings, when it became apparent that lecture would dominate the presentation of intervention material, I realized I was going to have to accommodate that. At the

same time, I wanted to continue to work to maintain the student-centered, model-based learning

theoretical framework. I tried two different strategies, adding small sections of lecture between

student-centered activities, and encouraging Eric to allow students to discuss, in small groups,

answers to questions he would pose, before opening it up to whole-class. I did not succeed in

either approach.

In the first instance, prior to the first iteration, I went back through the lesson outlines and

highlighted areas for Eric to "do the talking" about concepts. This included concepts (e.g. elastic

rebound theory), phenomena (the nature of P- and S-waves and the earth's internal heat), and

history (for instance, the seismometer and early maps of seismicity). I chose these sections

because they seemed to lend themselves more to direct instruction over student inquiry. Students

needed this information to continue their own model construction. However, the concepts were

difficult to observe first hand in a manner that would also satisfy the time constraints Eric

emphasized. These teacher-led sections would be a way to vary the context of the class and

expose students to important information efficiently. I intended each lecture section to last five to

10 minutes and be bracketed by questions to students about the progression of their models of

earth dynamics with regard to the introduction of the new information. In this manner, Eric could

maintain a sense of giving or leading, and I could also keep a focus on students making models

and testing them.

In describing the second approach, I often brought up to Eric the opportunities where he

could ask questions in a manner that garnered more response from the students, by letting them

discuss with a partner first, and then opening a discussion to the entire class. Eric did not pick up

this instructional tool. As an example, on the final day of the second iteration, when Eric was to

"bring it all together" by asking students how they would test the theory of plate tectonics, I

suggested that he ask students to work together in groups first and then report out to the whole

class. Eric agreed, but changed his mind within minutes of proposing the strategy. Eric began by

asking students to discuss "for a few minutes, together in groups," or to write in their notebook

how they would go about testing the theory of plate tectonics. Within a few seconds, Eric

proposed to students to not "feel constrained to write something down," and to "just throw ideas

at" him. After a pause of about ten more seconds, Eric began demonstrating that, by moving a

table, proof of plate tectonics would come from actually measuring plate motions.

In these cases, I was asking Eric to use teaching methods he was not used to; methods

that fostered student autonomy and maybe more unpredictability. I see now that these methods

did not fit into the structure of either metaphor. If I understood Eric's teaching metaphors earlier,

I might have emphasized different facets of the *puzzle metaphor* or the *fieldtrip metaphor* to

make student autonomy a more reasonable course of action. For instance, in terms of the *puzzle*

metaphor, I could have discussed students constructing their own "big picture," the same way

Eric spoke of them putting the pieces together for themselves. I could have had Eric create more

opportunities for students to draw their ideas, *their* big picture, in their notebooks, so Eric could

see them. This might open the window for him to see the variability of student understanding. He

could use "trends" in students' drawings to alter emphasis in his instruction. Eventually, he could

ask students why they drew the pictures the way they did. In this way, he could reflect on what

he said and how those ideas manifested in the students' drawings, and what that might mean for

making clarifications.

After analyzing this data, I realize I could have varied the *fieldtrip* and *puzzle metaphors*

into a *field camp metaphor*. Though not as predominant a teaching tool, geology field camp is

typically a summer long experience making a geologic map of a particular area or mapping

multiple areas through actual field observations. In field camp, there is no single path through the area to be mapped. Students look for areas that seem geologically significant and learn about those areas by making personal observations. They draw notes on their maps, move to the next area to do the same thing. Using this data, they try to project their ideas into places where they did not go. They could test their predictions by going to some of these places and see if their observations match. Students would usually work in pairs or small groups during this exercise. The role of instructors at field camp is to look at what the students are drawing and the inferences they are making and point them to "key locations" in the terrain that would help them with their interpretation. Students still cover the ground they need to, but are much more in charge of making their own maps (Turnbull, 1989) or, again, drawing their own big picture. In this metaphor, there is no final destination, or a particular order for covering the ground, but rather many points of interest with constant cycles of predicting and testing those predictions. Learning can continue as long as there is terrain that has not been observed.

Within this metaphor, Eric maintains his motivations of authority (knowing the terrain) and responsibility to students, though these will be shifted somewhat, as I discuss below. The difference is his choices of how to enact these motivations have changed due to the variation in the metaphor. According to this metaphor, Eric would have the opportunity to engage a shift in his dimensions of teaching (Bartholomew, Osborne, & Ratcliffe, 2004) and begin to centralize student activities over teacher activities.

Moving Toward "Teaching in the Making"

Bartholomew et al. (2004) outlined five dimensions of effective NoS teaching. Because teaching science content is no different than teaching nature of science as a kind of content, these dimensions work for science content as well. The dimensions they outlined were: teacher

knowledge, conceptions of their role, use of discourse, conception of learning goals and the nature of classroom activities. Within each dimension they evaluated their participants along a sliding scale from teacher-centered to student-centered. The scale of the first dimension, knowledge and understanding of content, ranged between "anxious" and "confident." Being a researcher in plate tectonics, Eric already had a strong knowledge and understanding of the content, and seemed very confident about it. The second dimension, teacher's conception of their role, was a continuum between "dispenser of knowledge" and "facilitator of knowledge." Structured by the *field camp metaphor*, Eric could begin to move from telling students what they needed to directing them to a location where they could get the information they needed. The third dimension, teacher's use of discourse, ranged from "closed and authoritative" too "open and dialogic." Eric could be asking students what they found at these locations where he sent them, and what it meant in the bigger picture, or for the map they were drawing. Their responses could then prompt him to point out new locations for more information as they refined their maps.

The fourth dimension of effective teaching described by Bartholomew and her colleagues (Bartholomew et al, 2004) was "teacher's conceptions of learning goals." This dimension ranges from "limited to knowledge gains," to "includes the development of reasoning skills." According to the *puzzle* and *fieldtrip metaphors*, Eric was responsible for students getting the pieces of the puzzle, or getting from A to Z, respectively. Employing the *field camp* metaphor, Eric would shift his responsibility to having students reason their own maps, make their own interpretations of the terrain. Students decide which directions are more fruitful and which ones are not. The last dimension described is "nature of classroom activities" and represents a continuum from "student activities are contrived and inauthentic" to "activities are owned by the students and are

authentic." Because Eric was presenting ready-made science in accordance with the *puzzle* and *fieldtrip metaphors*, the activities had to be contrived; structured with the end in mind. Within the context of the new *field camp metaphor*, Eric need not structure all activities but send students into the terrain with some tools (Brunton compass, rock hammer, bottle of acid, and maps) and let them be more self-directed. It would be through reflection and support, and increased comfort and confidence that Eric could move incrementally from the teacher-centered end of the continuum to the more student-centered. How Eric would enact each dimension has virtually limitless potential; something I would identify as "teaching in the making." This is in contrast to my attempt to impose on Eric "ready-made" teaching, where, in the end, the goal was to do what I had designed, with limited input from Eric and no real opportunity for negotiation.

New Metaphors for Teaching?

The idea of changing metaphors to change teaching is not new. Tobin and LaMaster (1995) described a case where a struggling middle school science teacher changed the metaphors she taught by and noted marked progress in the classroom atmosphere and effectiveness of her teaching. The participant in the study, "Sarah," described great difficulties teaching her classes, especially from a management standpoint. She reported that she utilized a metaphor of distance, in terms of classroom management and assessor. This seemed to be causing her difficulties. She assumed a metaphor of *social director* instead of classroom manager and a metaphor of *looking into her students' minds like through a window*, instead of assessor. What she found was this relieved a lot of the responsibilities she felt for controlling student behaviors and making sure they learned exactly what she wanted them to learn (also a form of control). Those responsibilities subsequently and appropriately placed with the students, Sarah's authority and

responsibilities shifted to other facets of her teaching and students responded favorably. This

allowed for much more effective classroom instruction.

Although Eric did not experience the management issues Sarah had, he often spoke of

"failure worries" in the context of students not learning the material even though they had "just

talked about it," or he had spent "three two-hour classes getting it across to them." He also talked

about his struggle with "grabbing control" or "letting students go." As the puzzle master, or the

field trip leader, Eric had the authority and made it his responsibility that students learned exactly

what he was teaching. The most efficient way to accommodate that, in his view and in

accordance with the two metaphors, was through direct instruction. A shift to field camp

supervisor would also have the effect of shifting the responsibility of student learning more

toward the student. Though he would maintain much of his authority, he instead would have

responsibility of guiding them in productive directions, let them struggle and maybe even flail.

Tobin and LaMaster (1995) identified Sarah's metaphors as "super-organizers" of her

actions in class. They found that she could reason from the metaphor to classroom actions and as

she acted in accordance to her new metaphors, her beliefs about her role, and her students' role

fell in line with the metaphor as well. One of the main points that Tobin and LaMaster made in

their article was the importance of administrative, collegial and research staff support for Sarah's

transformation. Also, though they did not mention it explicitly, Sarah was ultimately the driving

force behind her successful change. She knew she could do better. She had a model,

constructivism, in which to frame the transition, and she utilized it explicitly and reflectively

(Khishfe & Ab-El-Khalick, (2002) to guide her actions.

Conceptual Change as a Model for Metaphor Change

Change of the sort reported by Tobin and LaMaster (1995) or suggested for Eric, must have support from the instructor as well as the colleagues and administrators who help determine the culture of the teaching environment. It is not unlike thinking about conceptual change (Posner, Strike, Hewson, & Gerzog, 1985; Strike & Posner 1992). The person with the "common sense" conception, in this case the instructor, needs to experience dissatisfaction with the current concept. Eric would need to experience dissatisfaction with the *puzzle* and *fieldtrip metaphors*. Although he did acknowledge that "stuffing their heads full of information isn't necessarily most effective," he did not feel that activities that actively engaged students did more than just engage them. He also explained that students who did not learn from direct instruction, did not because they were not receptive to it. They were sleeping, absent, or on Facebook.

Besides dissatisfaction, Eric would also have to see that a replacement concept, or new metaphor, would be intelligible, plausible, and fruitful (Posner, et al., 1987). In addition to these constraints, Strike and Posner (1992) said it was necessary to understand the learner's motivations and conceptual ecology. This includes "such cognitive artifacts as anomalies, analogies, metaphors, epistemological beliefs" (p. 150), and other knowledges. This is very much akin to $PC_{xt}K$ but without the some of the social facets. This investigation has made meaning of the factors involved in Eric's instructional decision making and could be used as a first step toward accommodating a conceptual, or metaphorical change for Eric in his continued development as a teacher.

The themes of motivation (authority and responsibility) gave Eric a reason to make a decision. The $PC_{xt}K$ themes explain why he made the particular decisions he did. It is the analysis of the metaphors that explains why these particular themes out of all the themes possible

in Eric's PC$_{xt}$K, were influential. Eric did not talk about departmental constraints because the two metaphors put him in charge; handing out knowledge, leading a field trip. He talked about student receptivity but not making allowances for students' original, partial, or common sense conceptions, because the metaphors do not take student prior understanding into account. The metaphors allowed Eric to view the students as passive, or even needing him to be the authority; "you are the teacher, and you will teach me what is in the class." They could eat the food he cooked if they liked what he was preparing. In line with the *conduit metaphor* (Reddy, 1975), the onus was on the student to be receptive. There was only "so much gyrating" Eric could do because "you can't make them [students] care."

By analyzing Eric's metaphors, I have developed an explanatory framework for the meaning Eric made for teaching, learning and the nature of knowledge and the factors that were influential in his decision making; something that has not been done before. This is an important contribution, because the metaphor framework highlights the particular PC$_{xt}$K themes that were important or most influential for study and therefore can be used as targets for change, if change is warranted. It may not be Eric's epistemological beliefs that get targeted, but some other factor in his PC$_{xt}$K, or motivations. This can cause a change in practice and then result in a gradual shift in epistemology in the iterative and reinforcing manner of teaching in the making (also note the parallel to learning via model-based learning).

Strike and Posner described how conceptions bias a person's interpretation of their environment. Eric's ideas about the departmental expectations (though he spoke little of departmental influence) were also in terms of both metaphors.

if you gave them a bunch of disconnected data they would not be able to *put together a new hypothesis* to test because they don't, they don't think within that framework. They

haven't been trained to generalize, expand…it's sort of an unspoken rule [throughout the

department] that students should be able to answer fundamental questions about basic

systems…if you said, "ok here is a fine grained, well sorted, well rounded sand. Where

do you think that is, close to the mountains or far from the mountains?" And they should

be *able to walk through that* and say that's going to be far from the mountains.

(20120809:518-544)

As far as Eric was concerned, the goals of the department were in line with his own goals. Trying

to get him to change teaching style would be difficult with consistent pressure from within Eric

and also from the environment that he thought suggested his current strategies were what was

expected.

Recommendations

Based on the above described implications to this research, I would suggest the following

to those involved with education at the undergraduate level:

1. Curriculum designers must know and work collaboratively with participant instructors

   when developing innovative curriculum. They must concede to the implementation of

   teaching in the making as opposed to presenting ready-made teaching.

2. There needs to be an open and highly communicative relationship between designers and

   instructors during development, implementation, and evaluation of innovative curricula.

   This will help ensure a shared meaning for shared vocabulary and a shared understanding

   of goals and actions.

3. Curriculum designers need to understand and take into account metaphors used by

   instructors implementing their curriculum. They need to identify the metaphors explicitly

   and discuss the implications of their structuring effects.

4. Multiple metaphors for teaching will give a more robust understanding for the role of teacher, student, and knowledge, and should be utilized with teacher development. This must be done with the understanding that new metaphors for teaching will be effective as long as:

   a. the instructor has the experiential bases and finds them useful

   b. the instructor has a "need" to use the new metaphor (internal and/or cultural)

   c. the instructor reflects on the use of the metaphors and receives support to utilize them

5. The culture and metaphors of teaching science need to change to promote and value the kind of teaching that research reports as effective. This would include:

   a. institutional and departmental emphasis on effective teaching practices

   b. better alignment of labs with lecture (integrated instructional units)

   c. socialization of GTAs into effective teaching practices. They will be the eventual agents of change in higher education science.

   d. utilizing metaphors that reduce the role of objectivism and highlight the iterative nature teaching and learning.

Where Do We Go from Here?

The implications of this research and the recommendations made in light of its results open the door (metaphorically speaking, of course) to a number of different possibilities for extended research. First would be to see how Eric, or another geology instructor would experience teaching within the structure of a more constructivist oriented metaphor like the *field camp metaphor*, for example. Another line of research would be to open metaphor analysis to a greater population to see if there are trends in the types of metaphors used to describe teaching,

learning and science. This could lead to discerning if these metaphors might be influenced by discipline. For instance, Dodick, Argamon, and Chase (2009), through language analysis, discerned that scientists from traditionally experimental sciences such as physics and chemistry communicate about scientific methodology in a significantly different way than scientists of historical sciences (geology, evolutionary biology and cosmology). These differences may affect or be affected by metaphorical structuring and may then influence teaching in each of the disciplines.

Another avenue for inquiry would be to incorporate this kind of reflective analysis, in a sustained manner, into teacher education programs. Teachers could analyze the metaphors that guide their understanding of teaching, learning and knowledge and they, with support from teacher educators, could help highlight entailments, or associations, of the metaphor that strengthen reform-based teaching practices. This could lead to teachers developing and utilizing new metaphors, as Sarah did in the case described above. Finally, I would like to further develop my historical treatment of plate tectonics, with an instructor and the appropriate metaphor, to gain an understanding of how students would learn about earth dynamics.

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of the Benefits and Challenges of Using Cases. *Journal of College Science Teaching,
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APPENDIX

Date

Time	Student actions	Teacher actions	Classroom activities	Notes
12:00				
12:10				
12:20				
12:30				
12:40				
12:50				
1:00				
1:10				
1:20				
1:30				
1:40				

Use of data - **Da**	Use of analogy - **An**	Inquiry activity - **IA**
Model work - **MW**	Elicit model building - **EM**	Small group - **SGD**
Motivation - **Mt**	Elicit dissonance - **ED**	Whole class - **WCD**
Analogy - **An**	Response to students - **RS**	Reading - **Rd**
Visualization - **Vi**	Questioning - **Qs**	Lecture - **Lc**
Explanation - **Ex**	Demonstration - **Dm**	
Metacognitive - **MC**	Story telling - **St**	
Elicit prior knowledge - **EPK**	Example - **Ep**	
	Explain - **Ex**	

A-1 Classroom observation protocol

Interview questions for first interview:

1. What is your experience teaching? When did you start?
2. You have a nice way of talking about seemingly distantly related concepts and then tying them together in the end. Tell me about you ability to do that. Where does it come from? What are your influences?
3. Tell me about your interest in participating in this research.

Interview questions for the post intervention interview:

1. Tell me about your experiences teaching the various parts of the intervention.
2. What is your impression of how the students experiences the instruction?
3. Now that you have graded the final exams, can you talk about your impressions about the learning that students did as a result of the instruction?

Clarification questions about previous comments:

1. You have often alluded to the feeling that you "had to" use the text, even though you might question that feeling. Can you talk more about that?
2. Early on in the first iteration, you described the situation of trying to get students to answer questions as an "uncomfortable silence." Can you talk a little more about what you meant by that?
3. At one point, you said, "it is really challenging to try and sort- to deconvolve working on research and then trying to teach an introductory level is actually quite challenging going back and forth." Could you elaborate a little bit on what you mean by that?
4. I am wondering if you can talk more about your thought processes during this one incident on the last day of class of the second iteration. We had discussed letting students devise their own test for the theory of plate tectonics, and you started out that way, telling them, "what I would like you to do is get together in groups and discuss or write by yourself in your note book a test of this hypothesis. And don't feel constrained to write something down, just throw answers at me." Can you tell me about your thought processes that might explain why you changed from having students develop their own tests to telling them what those test should be?

A-2 Interview protocols

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EDUCATION

Ph.D. Science Education Syracuse University, intended completion May, 2013
  Dissertation title: The Barriers Encountered to Implementing Innovative Curricula in Introductory Geology Courses
  Committee: Dr. Sharon Dotger (chair) – Dept. of Science Teaching, Syracuse University
  Dr. John Tillotson – Dept. of Science Teaching, Syracuse, University
  Dr. Suzanne Baldwin – Dept. of Earth Sciences, Syracuse University
  Dr. Douglas Allchin – Dept. of History, University of Minnesota

M.A.T. Geology Binghamton University, December, 1995
M.A. Geology The Johns Hopkins University, May, 1990
B.S. Geology SUNY Binghamton, May, 1988

RESEARCH EXPERIENCE

Dissertation research: Using design based methodologies I am investigating how students build mental models of concepts surrounding the phenomena explained by the theory of plate tectonics. I am also investigating the decision making practices of the instructor who is implementing the instructional intervention emphasizing the use of historical case studies, historical documents and data and historically contextualized inquiry based activities.

Working on the NSF IMPPACT project I did qualitative analysis on many interview transcripts (multiple participants from each of three different universities) to understand how secondary science teachers made meaning of and utilized particular interventions within their teacher education programs. Also in another investigation on the same project, I focused on identifying teacher-participants' personal, student and scientific epistemology, through their use of metaphor, to gain understanding of the relationship between their epistemologies and classroom practice.

I investigated a lab group of four women in an introductory physical science class for preservice elementary teachers. This was a semester long study of their discourse (verbal and written) to discern the patterns of behavior that seemed to be inhibiting them from developing useful understanding of the course content. Included in this study was an investigation into how teacher, or teaching assistants' discourse and actions often reinforced student behaviors that were inhibiting the development of useful understanding.

I performed a semester long qualitative investigation of three brand new teachers who made up the entire secondary science department in a rural school. My goal was to understand how they experienced the conditions of teaching in a high-needs, rural school and how they identified the benefits and challenges of teaching in such an environment.

TEACHING EXPEREINCE

Teaching assistant: conducting independent lessons leading discussions and organizing guest speakers for a class of preservice secondary science teachers. SCE 631 – Nature of Science and Science Teaching – Syracuse University – Spring 2012, 2011, 2010, 2009.

Instructor: Conducting all lectures and activities for the five week qualitative methods portion of a survey course on research methodology for higher education masters and PhD students. HED 616 – Understanding Educational Research – Syracuse University – Fall 2011, 2010.

Instructor: conducting all lectures and activities for one section and assistant for a second section of an introductory physical science class for preservice elementary teachers. SCI 104 – Quests and Questions in physical science – Syracuse University – Fall 2008

Instructor: Conducting all lectures and activities for one section and assistant for a second section of an introductory physical science class for preservice elementary teachers. SCI 104 – Quests and Questions in physical science – Syracuse University – Spring 2009

Instructor: New York State Regents Earth Science teacher – Conducting all lectures and activities in high school Regents Earth Science. Union-Endicott High School, Endicott, New York – Fall 1996 to Spring 2008: New York State Public School Earth Science and General Science 7-12 Teacher Certificate: no. 087667490, control no. 694138961

Instructor: New York State Regents Earth Science teacher – Conducting all lectures and activities in high school Regents Earth Science. Elmira South Side High School, Elmira, New York – Spring 1996: New York State Public School Earth Science and General Science 7-12 Teacher Certificate: no. 087667490, control no. 694138961

Teaching assistant: Conducting all lab activities in an adult education introductory geology course – Johns Hopkins University, Baltimore, Maryland – Spring 1990

SERVICE

To department:

Professorial search committee graduate student member – Read through CVs and cover letters, met with other members of committee and interviewed applicants for science education teaching position. Fall 2009 to Spring 2010

To university:

Syracuse University – Kenyatta University (Nairobi, Kenya) HED Planning Grant Committee graduate student member: Interviewed SU faculty about program capacities and helped to draft and finalize SU-KU partnership grant. Traveled to Nairobi, Kenya to finalize grant proposal – 2010 to present

To profession:

Secretary: Association of Science Teacher Educators (ASTE); Northeast region – October 2011 to present

Graduate Student Representative on the Executive Council: International History and Philosophy of Science and Science Teaching Group (IHPST) – July 2009 to July 2011

Earth Science State Director at Large: Science Teachers Association of New York State (STANYS) – July 2001 to July 2008

Reviewer

Science & Education	2009 to present
International Journal of Science and Math Education	2012 to present
Association of Science Teacher Educators Annual Conference	2009 to present
National Association for Research in Science Teaching Int'l Conference	2009 to present

Professional affiliations

Association of Science Teacher Educators	2008 to present
National Association for Research in Science Teaching	2008 to present
International History, Philosophy & Science Teaching Group	2005 to present
Geological Society of America (GSA)	2004 to present
National Earth Science Teachers Association	2001 to present
National Association of Geoscience Teachers	1995 to present
Science Teachers Association of New York State	1995 to present
Earth Day Southern Tier	1996 to 2001
Board of Directors	1996 to 2001

PUBLICATIONS

Dolphin, G. (2012). Teaching at the intersection of cognitive science and the history of geology: using controversy to design instruction around the theory of plate tectonics. *Geological Society of America Abstracts with Programs, (41)*

Dolphin, G. (2009). Evolution of the theory of the earth: A contextualized approach for teaching the history of the theory of plate tectonics to ninth grade students. *Science & Education*, *(18)*, 425-441.

Remis, R., & **Dolphin, G.** (2008). Two birds, one stone: A discussion about the importance of the nature of science and how it parallels literacy in the science classroom. *Science Teachers Bulletin, (71)2*, 4-10.

Dolphin, G. (2006). STANYS big ideas teacher institute series. *Geological Society of America Abstracts with Programs, (38)7.*

Dolphin, G. (2005). Various titles. *Digital Library for Earth Systems Education New York Instructional Collection,* http://www.dlese.org/dds/histogram.do?group=subject&key=nyic .

Ebert, J., Kluge, S., Ross, R., Dawson, J., **Dolphin, G.**, Geary, E., & Barstow, D. (2005). New York State and the second revolution in Earth and space science education: Assessment of key issues and a call to arms. *GSA Abstracts with Programs, (37)1.*

Dolphin, G. (1998-2003). Science column. *Earth Times*, semi-annual.

Dolphin, G. (1997-1999). Science column, Much ado about nothing. *Kaleidoscope*, bi-weekly newspaper.

In Press

Dolphin, G. and Dodick, J. Addressing earth science content with HPS: Where teaching the controversy is a logical approach. In Matthews, M. (Ed.). *History, philosophy and science teaching handbook*. Dordrecht: Springer.

In review

Dodick, J. and **Dolphin, G.** Geological controversies: A role for history and philosophy of science in earth-science education, in Baker, V. (Ed.) *Geology's Fabric*. Geological Society of America Special Publication.

In preparation

Dolphin, G. and Dotger, S. How being a good student can inhibit meaningful learning.

Dolphin, G. and Tillotson, J. The rookies: A case study of three first-year science teachers in a rural school.

Dolphin G. and Tillotson, J. How the expressed epistemologies of secondary science teachers relate to their classroom practice: Implications for teacher education programs.

PRESENTATIONS

How the expressed epistemologies of secondary science teachers relate to their classroom practice: Implications for teacher education programs (**Dolphin, G.** & Tillotson, J.)
Association of Science teacher Educators 2012 international Conference, Clearwater Florida, January 2012
11th International History and Philosophy of Science and Science Teaching Conference, Thessaloniki, Greece, July 2011

How Being a Good Student Can be a Barrier to Meaningful Learning (**Dolphin, G.** & Dotger, S.)
Association of Science Teacher Educators 2011 International Conference, Minneapolis, MN, January 2011

The Rookies: A Case Study of Three First-Year Science Teachers in a Rural School
Association of Science Teacher Educators 2011 International Conference, Minneapolis, MN, January 2011

A Tale of Three Universities: How Preservice Science Teacher Experience Three Different Teacher Education Programs and the Development of their Beginning Repertoire
(**Dolphin, G.**, Jetty, L., Barry, D., Young, M., & Tillotson, J.) Association of Science Teacher Educators 2011 International Conference, Minneapolis, MN, January 2011

Visions of Good Teaching: A Qualitative Description of Teachers' Beliefs
(Jetty, L., Young, M., Barry, D., **Dolphin, G.,** & Tillotson, J.) Association of Science Teacher Educators 2011 International Conference, Minneapolis, MN, January 2011

Science Teachers' Beliefs about Reformed Teaching and Learning: A quantitative Analysis Using the BRSTL Questionnaire
(Barry, D., **Dolphin, G**., Jetty, L., Tillotson, J., & Young, M.) Association of Science Teacher Educators 2011 International Conference, Minneapolis, MN, January 2011

A Preliminary Examination of a New Instructional Model for Conceptual Change, Association of Science Teacher Educators 2010 International Conference, Sacramento, CA, January 2010

A Preliminary Examination of a New Instructional Model, International History and Philosophy of Science and Science Teaching Group 9th biennial conference, Notre Dame University, July 2009

Teaching Earth Science with Models, STANYS 113th, 2008

Two Birds, One Stone: teaching literacy and scientific literacy, STANYS 112th, 2007

Regents Earth Science Performance Test Turn-Key Training, Syracuse BOCES, October 2007

Evolution of the Theory of the Earth: A Contextualized approach to Teaching the Theory of Plate Tectonics to Ninth Grade Students, 9th International History, Philosophy & Science Teaching Conference, University of Calgary, Canada, 2007; STANYS 113th, 2008

…To Get to the Other Side: Teaching the Nature of Science, STANYS 111th, 2006

STANYS Big Ideas Teacher Institute Series, Geological Society of America Annual Meeting, STANYS 111th, 2006

Infusing Earth Science into the Elementary Curriculum, STANYS 110th, 2005; Binghamton Area Reading Council (BARC), 2006

Teaching with Models, STANYS 110th, 2005

DLESE New York State Earth Science Instructional Collection Development Workshop, Co-director, June 2005

Build Your Own Eurypterid, STANYS 109th, 2004

Across the Board Assessment, STANYS 108th, 2003

Delightful Discussions Devoted to D, Co-presented, STANYS 108th, 2003

Outside the Box, Co-presented, STANYS 107th, 2002

Earth Science Breakfast, STANYS 107th-112th, 2002-2007

The Climate and You, STANYS SAR planning meeting, STANYS 107th, 2002

Hands-On, Inquiry Based, Teaching Modules in Seismology, STANYS SAR Planning Meeting, Binghamton University, 2002

Shake, Rattle and Roll, Union-Endicott Professional Development Symposium, 2002

Science and Literature, STANYS (southern Section) Science Smorgasbord, 2001, 2002

Warning: This Session is of Graphic Nature, Math, Science, and Technology (MST) Annual Conference, 2000; STANYS, 106th, 2001

Not to Scale, Math, Science, and Technology (MST) Annual Conference, 2000; STANYS 105th, 2000

Dynamic Earth, Endicott Teachers' Center, 2000

A Thematic Approach to Teaching Earth Science, STANYS 104th, 1999

A Potpourri of Learning Styles, BEST Institute, Binghamton University, 1997

AWARDS, FELLOWSHIPS AND GRANTS

School of Education Creative Research Grant $460	Syracuse University, 2012
School of Education Conference $400 Travel Grant	Syracuse University, 2009, 2010, 2011, 2012
Graduate Student Organization $300 travel grant	Syracuse University, 2011, 2012
Marvin Druger Department of Science Teaching $600 travel grant	Syracuse University, 2011
Certificate of University Teaching	Syracuse University, 2011
National Center for Case Studies annual conference scholarship $500	Buffalo State University, 2011
Outstanding Teaching Assistant Award	Syracuse University, 2009
STANYS Award of Appreciation	STANYS, November 2008
Southern Section STANYS Service Award	STANYS, Southern Section, 2007
Educator of the Week	WBNG TV 12, 2004-2005
Who's Who Among America's Teachers	National Academic Affairs, 2003-2005
Outstanding Earth Science Teacher (Eastern Section)	Geological Society of America, 2003
Outstanding Earth Science Teacher (Eastern Section)	National Association of Geoscience Teachers, 2003
Outstanding Earth Science Teacher (New York)	National Association of Geoscience Teachers, 2003
Grant for Visiting Professional Speaker	STANYS, Southern Section, 2000
Outstanding Intern Award	Binghamton University, 1996
Ralph E. Digman Prize for Excellence in Geology	SUNY Binghamton, 1988