Toward an understanding of “teaching in the making”: Explaining instructional decision making by analyzing a geology instructor’s use of metaphors

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ABSTRACT

Research shows that teachers presented with new curricula designed to be more student-centered do not usually implement that curricula as intended, even when they receive associated professional development. To date, researchers have examined the implementation issue by focusing on teachers’ beliefs, knowledge, and motivations to explain their practices, although results are complex and sometimes contradictory. Similarly, this case study research investigates how a geology instructor (Eric, a pseudonym) chose to implement a student-centered, inquiry-rich, discussion-focused curriculum by using traditional teacher-centered strategies instead. Classroom observations and multiple audio-recorded meetings with Eric were a means to understand why he chose and amended certain parts of the proposed curriculum. The object of focus is Eric’s spontaneous use of metaphor when talking about teaching, learning, and knowledge to understand and explain the factors involved in his instructional decision making. Analyzing Eric’s conversations and teaching through an embodied cognition theoretical framework shows that he structured his teaching with two metaphors: the jigsaw puzzle metaphor and the fieldtrip metaphor. These parallel metaphors worked in concert to shape how Eric perceived his role, his students’ role, and the role and nature of knowledge; thus, they structured what and how he taught. Understanding teachers’ conceptual metaphors can aid curriculum designers to develop content with a higher likelihood of implementation, just as collaboration and communication between designers and teachers will support teaching-in-the-making.

INTRODUCTION

Determining why instructors implement curricular aspects in different ways would facilitate more effective curricular and teacher development. In this research project, I draw on a growing body of literature in the cognitive sciences and linguistics to build a novel approach for investigating how teachers implement curricula: specifically, the study analyzed an instructor’s metaphor use. This provided an effective lens to understand why a particular geology instructor intervened in a curriculum dense with student-centered activities, choosing instead to use a more traditional lecture-based format.

Geology is replete with metaphor, from “rock record” to “tectonic plate.” We use these metaphors as shorthand for understanding. We also use metaphor in instruction to help students develop understanding (Nersessian, 2008; Sibley, 2005). For instance, we often substitute space or distance for time when talking about Earth’s history (i.e., “deep time”). Where experts are much better at discerning meaning from the metaphor, novices often are not (Amin, 2009). Indeed, particular metaphors could act as a barrier to understanding for students, because students’ common understanding structures how they derive meaning from the metaphor (Taber, 2003). As an example, Dolphin and Benoit (2016) demonstrated how their student participants’ understanding of “tectonic plate” was actually grounded in their everyday experience with ceramic plates. Their separate and brittle nature precluded the students from developing a useful understanding of elastic rebound theory. This current research concludes that the geology instructor’s metaphors to describe teaching, learning, and students structured his understanding of how to teach and thus explains why he implemented an innovative, highly student-centered curriculum in a traditional, teacher-centered manner.

Fairweather (2008) asserted that student-centered curricula enhance student learning in science. Freeman and his colleagues (2014) echoed these findings in their review of 225 different studies, showing that students in traditional science, technology, engineering, and mathematics (STEM) courses were more likely to fail in a lecture-only class than one that promoted students’ active learning. Regardless of these results, traditional lectures continue to be the format for most introductory geology courses (Macdonald et al., 2005). However, curriculum developers, emphasizing active learning in their products, design as if teachers are only technicians (Barnett and Hodson, 2001), merely executing curricula as written. The result is that these curricula are seldom implemented as designed (Hullemann and Cordray, 2009). To explain why teachers pick up certain aspects of curriculum and not others, and why they teach the way they do, much current research has focused on linking teachers’ explicitly declared beliefs to their practice (Jones and Carter, 2007; Markley et al., 2009; Ryker, 2014). Some researchers have reported factors other than beliefs that account for why instructors implemented innovative curricula in ways that were not intended by the developers. Mansour (2009) asserted that contextual constraints influence how teachers...
implement curricular tools. Barnett and Hodson (2001) identified pedagogical context knowledge (PC_{\text{K}}) as a reigning factor in instructor decision making. Höttecke and Silva (2011) described the varied factors affecting teachers’ implementation of history and philosophy of science (HPS)–rich curricular tools, such as a "culture of teaching physics," physics teachers’ attitudes and beliefs about teaching physics, institutional constraints, and textbook limitations.

Orion and Ault (2007) also identified that "professional inertia" affects implementation. Markley et al. (2009) said many of their participants—postsecondary geology professors—did not think teaching practice had much impact on learning outcomes. They also proposed that professors needed intrinsic motivation to be good educators since the university system did not reward good teaching. Brown (2009) termed teaching a “design activity” (p. 18), an iterative process of implementation, testing, and amending curriculum. He 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).

This qualitative case study breaks with the prior research strategies by analyzing an instructor’s language as he talked about teaching, learning, and knowledge, incidental to the conversation at hand. I did not ask the participant instructor, Eric (a pseudonym), explicitly about his thoughts and beliefs about these concepts. Instead, I encouraged Eric to talk about his experiences with teaching and learning (his and his students’) and then analyzed what was implicit in his words, in tandem with observations of his practice. I argue here that this approach is superior to other methods noted in the literature review. By employing new understandings of the way the brain works (Shapiro, 2011), this approach explains why Eric made the pedagogical decisions he did, why lecture-based instruction seems so hard to move away from, and also gives a starting point for how we might develop more effective teaching strategies in undergraduate geology classrooms.

■ THE NEED FOR A NEW FRAMEWORK FOR ANALYSIS

To determine why instructors teach the way they do, researchers have used various strategies to delineate instructors’ beliefs (about teaching, learning, students, etc.) and the relationship between their beliefs and teaching practices. The outcomes of these inquiries have conflicted. Some participants describe beliefs that parallel each other, while other participants hold a multiplicity of beliefs. Some studies have shown that an instructor’s beliefs are consistent with her/his practice, while others have shown inconsistencies between beliefs and practice. The root of the discrepancies may be the nature of the instruments being used to understand teacher beliefs. In most cases, researchers ask questions explicitly about the participants’ beliefs concerning teaching, learning and science, or ask teachers to explain their practice. I invite the interested reader to view specifics of the studies used to make the above claims in Appendix 1.

While Luft and Roehrig (2007) feel that this method is reliable for ascertaining teacher beliefs, the limitations of this approach become obvious below, where I build an argument that most of our decisions are made automatically, structured by unconscious metaphorical understandings of the environment (Lakoff and Johnson, 1980, 1999). Explanations of such decisions are often created post hoc and accepted (and expressed) as causal espoused beliefs (Kahneman, 2011). The next part of this section supports a data analysis framework that more accurately explains and predicts practice.

The purpose of this section is to build an argument for analyzing a participant’s metaphor usage in order to explain his actions. The analysis of metaphor for this purpose is rare in the literature (Tobin and LaMaster, 1995; BouJaoude, 2000; Reeder et al., 2009). In these studies, metaphors were elicited explicitly (for instance, “what metaphor would you use to describe your teaching?”) as a tool for understanding participants’ beliefs about teaching and science. In this way, the strategy suffers the same limitation of a post hoc creation to rationalize practices. In this research, where I analyze this geology instructor’s use of metaphor to explain his instructional decision making, I utilize Eric’s automatic or spontaneous use of metaphor during his teaching, and our conversations inform on how he structured his unconscious reality. I then argue that this, in turn, framed certain teaching strategies as reasonable to him, while it constrained others.

A metaphor is a type of analogy that directly compares one thing, such as a concrete experience that is easily understood by most people, to another thing—a thing or experience that the user or speaker is trying to better understand (Nersessian, 2008). This latter item is called the “target” domain or concept, while the concrete thing is classified as the “source” concept. Reddy (1979) claimed that the semantic structures of the English language lead its speakers into a particular frame that creates barriers to effective communication. He explained this with an example: the conduit metaphor, where thoughts or ideas (target domain) are characterized as physical objects or things (source domain) that can be given and received (e.g., She tried to get her thoughts across to the audience, but they were not receptive to her ideas1.). Words are containers that can hold the ideas or thoughts (e.g., He spent a long time trying to put his thoughts into words.), and language is a conduit for transferring the ideas to someone else (e.g., It took a lot of persuasion, but I think I finally got my message through to him.). Reddy argued this metaphor structures how we use and understand communication, which manifests as expectations for the communicator and the listener (or reader).

Elaborating on Reddy’s (1979) work, Lakoff and Johnson (1980) claimed we gain meaning of the world through concrete, embodied experiences. They labeled this type of learning as “embodied cognition.” Because we cannot have concrete experiences with abstract ideas (love, mind, learning, etc.), we create that meaning for them by projecting our experiences with concrete things onto those abstract concepts, through the use of metaphor. For example, when we say, “I’m in love,” love is a hopelessly abstract concept, but the brain conceives

1 Throughout this paper, to note textual metaphors in sample sentences, or quotations from Eric (the participant), I will italicize the text to identify the metaphor. Such italicization appears most often in the Findings section where I quote Eric several times. Please note that this is distinct from any typical usage of italics elsewhere to emphasize a word or idea.
tualizes it, in this case, as a bounded container, a concept with which we have many experiences (a can, a bottle, a bathtub, etc.). Recent neurologic studies utilizing functional magnetic resonance imaging (fMRI) indicate the brain does not perceive metaphors as a language device. It derives meaning of “in love” from our embodied concrete experiences with the insides of containers (Gallese and Lakoff, 2005). Our mind perceives love, in this case, as a bounded container (a common experience, as with cans, buckets, and pools) that we can enter into, explore, and fall out of.

Grady (1998) and Lakoff and Johnson (1999) asserted that we develop many primary metaphors based on early concrete experiences and then create compound metaphors by combining primary metaphors; in this way, we project concrete meaning onto abstract concepts. Importantly, the metaphorical projection is automatic, unconscious, and systematically highlights and hides aspects of the target (abstract) concept (Lakoff and Johnson, 1980). Metaphorical projection takes place via our cognitive unconscious and embodied mind (Lakoff and Johnson, 1999). Kahneman (2011) described this as “system-1 thinking.” System-1 thinking is responsible for such activities as orientating yourself in space, doing routine activities, and recognizing stereotypes and metaphors. It also controls associative activation, where exposure to one idea or metaphor triggers many other related ideas in a “spreading cascade of activity” (p. 51) creating a “vast network of associated ideas” (p. 53). This was also referred to as a metaphorical gestalt (Lakoff and Johnson, 1999), influencing that person’s perceptions of reality. Tobin and LaMaster (1995) used this idea to foster change in how an in-service teacher taught, by changing the metaphors underpinning her understandings of teaching and students. I argue here that it was Eric’s spontaneous use of two compound metaphors for teaching that structured his reality of teaching introductory geology. The metaphors both highlighted his traditional style of teaching and suppressed the more student-centered approach of the curriculum.

Drawing on this embodied cognition theoretical framework, I sought to answer the following 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 us 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 student-centered, inquiry-rich, and historically contextualized curriculum?

■ METHODS

This research investigates the instructional decisions a geology instructor, Eric, made while implementing a curricular intervention. The purpose of the intervention was to facilitate student mental model building within the context of the theory of plate tectonics and to foster a more robust understanding of the nature of science (NoS). The research took place at an R-1 university in the northeastern United States, during two undergraduate introductory geology courses taught in two sequential summer terms in 2012. I engaged in two lines of inquiry—student conceptual development and instructor decision making—within the structure of a multi-tiered teaching experiment (Lesh and Kelly, 2000). This means it was similar to an intervention study but with constant analysis and the freedom to manipulate variables (teaching, curriculum, etc.) to better reach the learning objectives. This paper reports only on the results related to instructor decision making. The design of the intervention included student-centered activities such as mental model building, small group discussions, and argumentation within the context of the historical development of the theory of plate tectonics. Between classes, Eric and I met to discuss the progression of the intervention and any changes needed, based on classroom observations.

■ Data Collection

As a participant observer, I took field notes and audio-recorded classroom instruction of the intervention (totaling 15 two-hour classes). My status as a participant observer meant that I would observe class activities, but I also participated to a limited extent in the activities, whether this was to answer student questions, interject ideas, or ask students what they were thinking during activities. Participating in this minimal way normalized my presence in the classroom, so that both the students and Eric felt more comfortable. This, in turn, facilitated normal interactions, and student and teacher behavior in the classroom. My focus was student-teacher and student-student interactions during student model building. I developed an observation protocol, divided into columns—“instructor actions” and “student actions.” Within these columns and based on the time of occurrence in class, I recorded observations of actions, such as “use of data” (Da), “analogy” (An), “explanation” (Ex), “questioning” (Qs), etc. There were a total of 22 different actions for recording. I also audio-recorded 19 planning and/or reflection meetings with Eric, lasting from 10 min to over one hour each. During these meetings, I also took the opportunity to ask Eric to clarify particular statements he made in previous meetings or in class. I transcribed the audio recordings and analyzed the data through Eric’s use of metaphor.

■ The Intervention

The intervention (that is, the student-centered curricula the instructor was to adopt) employed various instructional strategies to facilitate learning about earthquakes and their relationship to the theory of plate tectonics. It was a product of “braiding” the history of science with inquiry- and model-based learning (MBL). In this case, “braiding” means that aspects (or strands) of the curriculum (history, inquiry, and MBL) were designed to flow from one to the next, with the
history setting up the inquiry and guiding its trajectory (Allchin, 2014). Student participants in each of the two classes were to experience five days of historically contextualized discussion and inquiry-rich content concerning the history of seismology and its role in the development of the theory of plate tectonics. The planned sequence of content and activities were as follows:

1. **Historical Prelude, Inquiry Activity, MBL**
   - The 1906 earthquake in San Francisco, encountered through the personal accounts of William James (1911) and Jack London (1906).
   - The Lawson Report (Reid, 1910).
   - Discussions on the above.
   - Through a concrete functional model (Boulter and Buckley, 2000)—an earthquake machine (Hubenthal et al., 2008; https://www.iris.edu/hq/resource/redefining_an_earthquake_v12)—students explore the elastic rebound theory (Reid’s mechanism for earthquakes). The model consists of a block of wood (2” × 4” × 4”) with sand paper affixed to the bottom (4” × 4” side) and a rubber band attached to a side that is used to pull the wood block across a length of belt-sandpaper fastened to a table top. Students pull the block along the sandpaper with the rubber band, which allows for a “stick-slip” behavior as elastic potential is built up in the rubber band and is then released when the friction of the block on the sandpaper is overcome.

   Through this activity, students analyze the model as a system of blocks, sand paper, and rubber bands, and all the forces and other variables at work within it. They can develop questions that they then answer by manipulating the model, collecting data, and making an evidence-based claim about the model. Once they are familiar with all the aspects of the model, they map aspects of the model onto reality, ideally deriving understanding of the role of elastic strain and rebound in the making of an earthquake.

2. **Historical Interlude, Inquiry Activity, MBL**
   - Analyze and discuss Robert Mallet’s (1858) map of global seismicity for possible patterns of seismic activity.
   - Develop their own models to explain their observations.

3. **Historical Interlude, Inquiry Activity, MBL**
   - Read about different models of Earth dynamics, such as the porous earth (Şengör, 2003), contracting earth and land bridges (Dana, 1847; Suess et al., 1904), expanding earth (Jordan, 1971; Carey, 1976) and horizontal displacement (Wegener and Skerl, 1924). Each idea answered some of the data.
   - Students needed to determine the implications of each explanation and how they might test each one.

4. **Historical Interlude, Inquiry Activity, MBL**
   - Explore different maps of seafloor data (similar to Sawyer [2002]), while learning about the history of seafloor exploration (Lawrence, 2002; Höhler, 2003).

5. **Historical Interlude, Inquiry Activity, MBL**
   - Discuss the development of World Wide Synchronized Seismic Network (WWSSN) in reaction to nuclear test ban treaty and the implications to the new wealth of seismic data.
   - Use the IRIS Earthquake Browser to refine students’ understanding of the patterns of global seismicity.
   - To further refine their model of Earth dynamics, students employ learning strategies such as “what-if” questions (Khan, 2008). After reading portions of Hess (1962) and Vine and Matthews (Vine and Matthews, 1963; Vine, 1966), they start to develop a model consistent with the current theory of plate tectonics.

   The sequence of activities, readings, and discussion (Fig. 1) parallels portions of the historical evolution of the theory of plate tectonics. This pattern demonstrates the iterative nature of scientific knowledge development and the role of wrong turns and false starts. Students are not given activities where they already know the outcomes, and thus only work to rationally reconstruct the known history (Allchin, 2013). Rather, they experience the sense of discovery as they ask their own questions and work through them to find answers. The inquiry is open but constrained by the history (Allchin, 2014).

   The original study was intended to look at how students developed their own models of plate tectonics within a learning environment engineered for mental model building (Boulter and Buckley, 2000; Clement, 2008b) through a series of historical case studies (Allchin, 2014) in the form of interrupted cases (Herreid, 2007). Having become familiar with the curricular intervention, Eric volunteered to implement it in his two summer geology courses. Eric received no formal professional development prior to implementing the curriculum as we only discussed how to approach leading a discussion or an inquiry activity.

**The Participant**

Eric, a professor and researcher in the field of plate tectonics, was teaching two introductory courses in geology. Aware of my desire to implement new curricula, he approached me about implementing it in his summer courses. During a later interview, he maintained that he was motivated to learn new ways to teach and engage students. Eric described his trajectory from undergraduate to graduate student, to holding a postdoctoral research position at a research-intensive university, followed by a position as a research scientist.
Figure 1. Graphic organizer depicting the iterative structure of the intervention. Driven by essential questions, activities have historical contextualization (Interludes), followed by an inquiry activity, and then student mental model building. Model building is then followed by another historical interlude. Abbreviations: MWH—Multiple working hypotheses; WWII—World War II; WWSSN—World Wide Synchronized Seismic Network.
at an international lab. He eventually made his way to a professorship at the current institution. From informal observations of Eric’s teaching prior to the investigation, I found him to be a very engaging speaker, using stories, well-thought-out explanations, and plenty of analogies including multiple metaphors to relate difficult concepts to students. He seemed to relate well with many of the students before and after class. That being said, his lectures were decidedly one direction—going from professor to students with little to no student interaction during the entire two-hour class period.

Data Analysis

During the data collecting period, I began analyzing Eric’s teaching and discussions for clues to help explain why he seemed to choose more traditional modes of teaching as opposed to the more student-centered mode called for by the curriculum. His practices contradicted his statements about using more reform-based teaching methods: letting students do the work, “letting them put the pieces together.” As I looked at the transcripts, I noticed that Eric utilized language coherent with Reddy’s (1979) conduit metaphor (ideas are things, words are containers for those things, and language is a conduit to transfer the containers from one person to the next). Jensen (2006) stated that “metaphors are a valuable research tool for gaining new insights into education practice and theory” (p. 49), because “the researcher is able to enter into the inner world of the perceptions, understandings, and experiences of the participants” (p. 41). With this in mind, I began to consider Eric’s use of metaphor within the context of teaching, learning, and knowledge. 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. I familiarized myself with some of the more common primary metaphors described by Lakoff and Johnson (1999) to help in this process.

A particular aspect of metaphorical language Lakoff and Johnson (1999) described is the emphasis of motion as part of the metaphor. It is very common for us to experience a subject that moves with respect to a stationary background, and so this aspect is common in our metaphors. For instance, “time is passing me by” has time as the subject moving relative to me, the background. I noted this aspect of motion in the metaphors Eric used. Not only did Eric describe the motion of knowledge to the students but he also repeatedly talked about “taking students through” a particular topic, having students make “a leap... a conceptual leap.” He would “pull them into” a topic or “keep them on track.” In general, Eric described knowledge (subject) moving with respect to the students (background), or the students (subject) moving with respect to knowledge (background). This subject/background relative motion became the criterion upon which I built the two compound metaphors discussed below.

The process of forming the two compound metaphors followed this trajectory. Starting from two overarching metaphor systems—“mind is a body” system and “event-structure” system, each divided into multiple primary metaphors—I categorized the vast majority of the narrative transcript passages (~400 passages, or 90%) into four primary metaphors: (1) thinking is manipulating objects; (2) thinking is moving, descending from the mind is a body system; (3) events are objects; and (4) events are locations descended from the event-structure system (Lakoff and Johnson, 1999).

Once classified, I subdivided each primary metaphor group into four to six subgroups based on the nature of the text. I based the subgroups on what Lakoff and Johnson (1999) identified as “entailments.” Entailments are the associations or implications we link to a metaphor, derived from our commonplace cultural knowledge of the source of the metaphor. For example, Lakoff and Johnson (1999) pointed out that if thinking is manipulating objects, then ideas are manipulable objects, understanding is grasping, communicating is sending, and memory is a storehouse. From the primary metaphors and their entailments, I discerned two compound metaphors. In terms of the subject/background relationship, the first emphasized the movement of knowledge in the form of puzzle pieces (subject) with respect to the students (background). I identified this as the jigsaw puzzle metaphor—a compound metaphor of “thinking is manipulating objects” and “events are objects.” The second compound metaphor emphasized the movement of students (subject) against the field of knowledge (background), where they can cover a lot of ground. I identified this as the fieldtrip metaphor—a compound of the “thinking is moving” and “events are locations” primary metaphors.

Figure 2 gives an illustration of the relationships among the systems, primary metaphors, and resulting compound metaphors. The compound metaphors incorporate the associations and extensions (entailments) of the four primary metaphors described above. Mapping the entailments refers to matching aspects of the source domain (e.g., storage facility) to aspects of the target (e.g., learning in the mind) based on Eric’s words (building them a memory palace). Figures 3 through 6 show the four primary metaphors, their individual entailments, and examples of Eric’s use of them. I demonstrate below that Eric’s use of these particular metaphors explains the teaching choices he made because the structure of each source domain (jigsaw puzzle and fieldtrip) emphasized certain teaching strategies, while simultaneously subduing others.

I also grouped ~20 passages in the “thinking is perceiving” primary metaphor, fewer in the “thinking is eating” primary metaphor, and ~10 fit the “existence is being located here” primary metaphor. Finally, there were ~10 passages that I could not classify into any particular group of primary metaphors.

It is important to reiterate here that, contrary to the explicit use of metaphor by participants in other investigations, Eric’s use of metaphor was completely spontaneous during the study period. At no time did I elicit Eric to use metaphorical language to describe his teaching or how he understands student learning. Nor did I discuss Eric’s use of metaphor with him at any time during the data collection period. Doing so would have jeopardized the reliability of the analysis (Morse et al., 2002), because Eric would have become self-conscious to his use of metaphor and possibly altered it in light of that self-consciousness.
Subjectivity Statement and Analysis Reliability

Formally schooled in geology, I worked as a professional geologist prior to being trained and then working as an Earth science teacher in a ninth grade, public school classroom. I designed the current intervention based on lessons developed during that decade-long teaching career (Dolphin, 2009). The lessons used history and philosophy of geology to encourage student inquiry, discussion, collaboration, argumentation, and model building and critique.

When I compare my activities as an academic researcher with my previous professional experience as a geologist, I find that qualitative research—such as this investigation—is remarkably parallel to geological fieldwork. In fact, education researchers call the space where we collect our data, “the field.” In essence, I collect empirical data (observations and audio recordings) and analyze the data with the intent to discern patterns and ultimately construct, inductively, an explanation for those patterns. As a geologist, I might venture into the field with multiple working hypotheses, which I then narrow down as the data demand. Or, I may enter the field with a theoretical framework already in mind (like plate tectonics theory for the geologist, or embodied cognition for this particular paper), which directs me to know what I should even consider data. When the theory leads to meaningful geological observations, this explanatory power reciprocally demonstrates the reliability and validity of the theory (Thagard, 2012). Or, from another angle, how well does the theory respond to the data, compared to other possible explanations? Just as geologists might make arguments about the reliability of their data and the conclusions they draw from it,

Figure 2. Structure of metaphor grouping. (A) shows the general progression from conceptual system (light-blue rectangle), broken into primary metaphors (purple rounded rectangle; see Figs. 3–6 for more detail) and entailments (white rounded rectangles), determination of the figure/ground relationship (yellow oval), then assembly of compound metaphor (green oval). (B) shows the specific primary metaphors under consideration, figure/ground relationships that guided grouping the primary metaphors into compound metaphors, and their entailments. (Key to passage identification for Figures 2–6: 20120809:224 is 8 August 2012 recording date, line 224 in transcript.)
they are starting with a framework in which they can begin to hang that library full of facts, to shelve those things. 20120809:224

then reworking it and molding it and shaping it and plucking it, until you get. “OK, this part seems to hold. This works so now I can take this and, and try to expand that part of it.”

starting to pull apart fluctuations in earth’s magnetic field 20120526:406

Memory is a storehouse

Ideas are manipulable objects

Thinking is manipulating objects

Communicating ideas is taking apart objects

Understanding is grasping

The structure of an idea is the structure of an object

Is there anything you want me to hold back? 20120526:257

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

Figure 3. Thinking is manipulating objects primary metaphor (dark-purple, rounded rectangle) and its entailments (white rounded rectangles) supported by Eric’s quotes (white rectangles).

similarly, qualitative education researchers also make such claims. I invite the interested reader to view Appendix 2 for an expanded section on my line of reasoning for the reliability and the validity of the results presented in this paper.

FINDINGS

A Tale of Two Metaphors

This section presents my analysis of Eric’s use of metaphor through the lens of embodied cognition as described by Lakoff and Johnson (1980, 1999). As a reminder, our understanding of the world comes through our embodied awareness of it. This means we have embodied experiences, received through our senses. To develop meaning for abstract concepts (those we cannot experience concretely), we project our experiences with the concrete onto the abstract through the use of metaphor. This use of metaphor is automatic and unconscious, and in turn, structures the target domain (abstract concept) in terms of the source domain (embodied experience) (Lakoff and Johnson, 1980). When Eric talked about teaching, learning, and science, he did so within the context of two separate compound metaphors. I identify them as the jigsaw puzzle metaphor and the fieldtrip metaphor. They incorporate the associations and extensions (entailments) of the four primary metaphors described above. Mapping the entailments refers to the matching aspects of the source domain (e.g., storage facility) to aspects of the target (e.g., learning in the mind) based on Eric’s words (building them a memory palace). I argue next that Eric’s use of metaphor explains the teaching choices he made because the structure of each source domain (jigsaw puzzle and fieldtrip) afforded him certain teaching tools while constraining others.

Eric’s Use of the Jigsaw Puzzle Metaphor

Oftentimes, when Eric spoke of teaching or learning about plate tectonics, he spoke of it in terms of “a puzzle” whose “pieces” he would “give out” to students. Subsequently, students had the responsibility to “receive” and “store” the pieces and “put them back together.” This metaphor incorporates entailments of both the thinking is manipulating objects metaphor and the events are objects metaphor (Figs. 3 and 4).

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 our discussions, Eric referred to details or scientific 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 [20120620 is date of recording; 36-40 is line number in recording transcript])

where what they’re (students) 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)
In Eric’s mind, he was giving (communication is sending) pieces of content (ideas are manipulable objects), and students would learn more than just the shape of those pieces (the structure of an idea is the structure of an object). It was then up to the student to put them together to make their own connections (synthesis is putting together).

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 events are objects primary metaphor where pieces of information are attributes, possessed by the whole puzzle. To affect learning in his students, he gave information (causation is a transfer of possessions) to them, or pieces (attributes are possessions) of the plate tectonics puzzle. Students would learn (achieving a purpose is acquiring a desired object) and connect the pieces (synthesizing understanding is putting objects together), 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. Importantly, the shape of the pieces of a jigsaw puzzle is already set, unchanging, just as the facts of plate tectonics, to Eric, were already set, unchanging. As is also characteristic of jigsaw puzzles, there is only one correct and ready-made solution. For Eric, he gave the set pieces, and students would put them together in the set way, developing an understanding for plate tectonics that was identical reality, just like the puzzle is identical to the picture on the puzzle box.

The puzzle metaphor is consistent with the belief that truths about the world exist separately from the mind—objectivism. The final picture of plate tectonics was the only correct answer. The structure or shape of the pieces, each a discovered effect of plate tectonics, was also certain. In other words, the

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1The use of the term “objectivism” is in the context of an epistemological stance. It is a descriptor of how one understands the nature of knowledge. As such, if one has an objectivistic epistemology, (s)he views objects and ideas as having intrinsic meaning that is universally understandable regardless of background knowledge, culture, or bias. It is explained fully in Lakoff and Johnson (1980).
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 ...20120620:43

And then, and then, and that’s the thing they start seeing; the contortion that people put themselves through defending their model. 20120614b:189

Dolphin | Analyzing instructor metaphors

Figure 6. Events are locations primary metaphor (dark-purple, rounded rectangle) and its entailments (white rounded rectangles) supported by Eric’s quotes (white rectangles).

Eric’s Use of 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 through space. These experiences, then, become the source upon which we draw to make sense of events such as learning that take place in our lives. Fundamental to the fieldtrip metaphor is the idea of traveling intentionally 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. Mapping Lakoff and Johnson’s (1999) outline of the important aspects of making a purposeful journey onto the concept of learning about plate tectonics, in this case, looks like this: The purposeful journey has a plan (course 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; and 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) and what stops (individual concepts) there are and how long will be spent at each stop.

The fieldtrip metaphor is a compound of the thinking is moving and the events are locations metaphors (Figs. 5 and 6). Based on the data, Eric saw it as his responsibility to “cover a lot of ground;” keeping students “on the path” with “benchmarks” and “guidelines” so they would not “get lost.” He sought...20120611:b124

Data speak for themselves, with no room for individual interpretation (subjectivism). Just as a jigsaw puzzle has a ready-made (preexisting) picture, so the students would experience ready-made science (Latour, 1987).

The source of this metaphor may be, in part, from Alfred Wegener’s reference to the “jigsaw puzzle fit” of the continents when he proposed continental drift as a model for the origin of continents and ocean basins (Wegener and Skerl, 1924) and the ubiquity of this metaphor in geology textbooks. Eric, a researcher of plate tectonics, perceived the theory as the way to order apparently disparate pieces of data.

... 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 1970s. He thought students should be able to simply and logically put the pieces together. The difference is that since the inception of the idea of horizontal displacements of the continents, scientists had many pieces, and they were using them to create the jigsaw puzzle (Frankel, 2012). To do this, some of the pieces may have needed shaping to get them to fit, as the whole puzzle continued to change shape. Eric taught only relevant data, the pieces that came directly from the finalized puzzle, in the manner of rational reconstruction (Allchin, 2013).
to “expose them to the background material” when necessary, and to prevent them from “flailing” by helping them make “forward progress.”

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 [teaching assistant] 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 ... without diverging too much from last time. [20120705:123–229]

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...” with them [20120705:300].

I feel like they potentially get more out of an intro class that teaches them and guides them toward a way of thinking... And if they are interested students that, and come back to take more classes...at least they are starting with a framework in which they can begin .... [20120809:214–225]

In his view, Eric guided (communicating is guiding) the students along a path (line of thought is a path). 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 and continue the journey.

In the following passage, Eric shared that the textbook also provided a kind of aid along the path.

It (textbook) 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 textbook 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, helping them along the path. The text could help drive discussion and lead students to a certain point keeping them from getting lost. This is consistent with other statements Eric made, 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 reach their destination.

Of course, with all journeys, there is the possibility of obstructions or barriers. Students must devise a way to overcome impediments to further their 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 intellectually get [sic] 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. [20120611:b:240–243]

In Eric’s view, the geologists’ vocabulary posed a formidable obstacle to the students. Without a working knowledge of the language of geologists, even if there was conceptual understanding, lack of vocabulary 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. He attributed this structure to his teachers and indicated that it 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 favored structured instruction to keep students on track as opposed to student-centered instruction, because any “self-direction” would ultimately lead to “flailing” in the wilderness.

As with the jigsaw puzzle metaphor, determining the implications of the fieldtrip metaphor is important in understanding the motivations in Eric’s instructional decision making. It made sense that Eric should plan the appropriate stops, guidelines (structure), and benchmarks (facts) along the way, so students could “get from A to Z” (step by step motion) and reach their destination (ideas are locations).

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 (ideas are locations) for students. They may even have to make jumps (actions are self-propelled motions) to keep progressing. Eventually, students will have made all of the stops from A to Z and reached their destination (states are locations), 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. As with any fieldtrip, the path, the stops, and the destination are already well blazed and interpreted (ready-made) by the fieldtrip leader. The role of those taking the fieldtrip 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. If theycontinue in a straightforward manner, from stop to stop, eventually, at the end of the trip, they will have an understanding of the ground they covered.
Motivated by Authority and Responsibility

Eric described himself as the holder of the puzzle pieces. He stated that the students needed 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.

Eric expressed that 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 asserted, “They don’t want to disappoint me” (20120809:66). He also perceived that they expected to receive the knowledge he and the textbook had to give. He characterized the students’ mindset as, “you are the teacher and you will teach me” (20120614b:20) and that they considered the textbook as a “security blanket” (201208:434), grounding course material in the truth.

In addition to authority, Eric intimated a sense of responsibility to his students. Eric said that he was “always looking for better ways to engage students” (20120611b:348–349). Eric perceived his responsibility to cover as much territory (content material) as possible, get through the journey on time, and not let anyone get lost. He was teaching “a massively accelerated course” (20120705:267). This meant there was no time to allow self-direction for students. Eric also stated that students wanted boundaries. Just as they wanted him to give pieces of information, he thought 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 setup 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 asserted his students perceived that the structure of the class was purposeful, and they were not allowed (or did not desire) to go out of those boundaries, 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 to make the path more obvious. He thought that self-direction would lead to flailing and slow forward progress. He did say that he wanted to get his students to a point where they could let go of the structure; where they would have the freedom to go on their own. However, Eric saw this as a goal because he envisioned only one ready-made path to understanding. It would be so obvious to students that they would not need structure or guidelines. As with the jigsaw puzzle metaphor, the fieldtrip metaphor also foregoes any independence of the students to think and derive meaning on their own; there was no opportunity (or need) for students to blaze their own trail (see the discussion about objectivity, below).

DISCUSSION AND IMPLICATIONS

Eric referred to teaching, learning, and knowledge in terms of the jigsaw puzzle metaphor and the fieldtrip metaphor. It is reasonable to associate the experiential basis of these two metaphors with the “jigsaw 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 jigsaw puzzle metaphor, a theory is the big picture or whole puzzle. The facts that made up the theory are 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 fieldtrip metaphor, the theory was the ground over which the fieldtrip participants navigated. Facts were designated stops and 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 parallel each other in a number of ways. First, both metaphors make 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 jigsaw puzzle metaphor, Eric, and the textbook, possessed the big picture—or puzzle—and both could break it down into smaller pieces of knowledge. He saw his role as giving these bits and pieces of knowledge to the students; the students’ task was to put them back together. According to Eric, this should be a relatively straightforward task because, as with puzzles, 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 fieldtrip metaphor, the path that was already made. Eric led the trip and designated and interpreted the stops. In addition to authority, he also had the responsibility of getting the student through the course on time. To do so, he “might have to be a bit [intense] about rolling through lecture” (20120705:558). He structured 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. These examples would appear to give students freedom to create their own, personal knowledge (a constructivist approach to learning). But again, in the context of the metaphors, the pieces and the puzzle were already set, and the path was well trodden over a known terrain. Students should understand the logic of following the path as with putting the pieces together. Thus, the implication for both of these metaphors reflects instead the notion that scientific ideas, or knowledge, exists independently of the human mind (objectivism); that facts 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 was already blazed. Learning should be straightforward, simply a matter of fitting the pieces together, or keeping on the path with 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 is done. By looking at the language Eric used during our discussions, I discerned patterns of how Eric unconsciously structured his reality with respect to those topics. Those structures were consistent and paralleled his actions throughout the entirety of the investigation period. Even in places where Eric seemed to contradict his actions with his words, the inconsistencies disappear when taken in the larger context of his metaphorical structuring. By contrast, much of the teacher beliefs literature (Appendix 1) reports on researchers asking explicitly about participants’ beliefs. Kahneman (2011) described how, when asked, people often rationalize their behaviors, post hoc, by making up a reasonable explanation, and then believing what they just made up. One can only surmise that this post hoc, by making up a reasonable explanation, rationalize their behaviors, and then believing what they just made up. One can only surmise that this post hoc reasoning may explain why researchers have difficulties in understanding educational practices.

What the Metaphors Afforded

The metaphors Eric utilized made some instructional tools more reasonable than others. The jigsaw puzzle and the fieldtrip metaphors allowed Eric a position of authority, as holder of the pieces of knowledge or as fieldtrip leader. In both cases, he had the authority and responsibility to give the pieces of information to students or to lead and interpret stops along the path. His role in both metaphorical structures made direct instruction reasonable. Students received or followed. As such, the tools most appropriate to Eric were lecture and discussion, as he identified it. In actuality, discussion was simply lecture without PowerPoint support. Over the two iterations (11 total classes), Eric lectured almost the entire time. Most lectures lasted close to the entire period except during those classes where the four approximately hour-long activities took place. In those instances, lectures were 30-40 min.

Because Eric already possessed 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 plate tectonics as a possible explanation. His teaching was “cleansed” of the errors of thought, dead-end investigations, and incomplete data of the past (Allchin, 2013). Allchin described this way of teaching the history of science as a “rational reconstruction.” It is this manner of teaching that misleads students’ understandings about the nature of science by picking out only the data that answers the pertinent question and presenting it to students who already know and who therefore only need to verify the answer. Instead, Allchin argued for giving examples of science-in-the-making (Latour, 1987) that were complete with its uncertainties. This approach demonstrates respect for the historical context, complexities and controversies, and to explain errors instead of purging them from history.

Reading was another tool Eric chose often. Most readings were from the textbook. This was an important tool for Eric. In contrast to a more subjective understanding of knowledge, where words are interpreted and quite possibly not as the writer intended, this approach considered 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 information. The text had a certain authority of knowledge but was a “crutch.” Though Eric considered many of the curriculum’s historical readings to contain a “personal entry,” or “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.

Eric did take up two of the inquiry activities called for by the curriculum intervention—the earthquake machine (Hubenthal et al., 2008; http://wwwiris.edu/hq/resource/defining_an_earthquake_v12) and the seafloor data activity (Sawyer, 2002; http://plateboundary.nic.edu/). The earthquake machine was new to Eric, but an activity very similar to the seafloor activity was already incorporated with the laboratory portion of the introductory geology courses. For the first iteration, he implemented both without any written directions or worksheets for the students. There were no written questions to answer at the end. Students performed these activities with varying levels of engagement, although 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 might not derive the appropriate knowledge they needed. As a result, for the second iteration, Eric asked that some instructions and some questions...
be added to the activities to help “direct” students. The structure helped to “streamline” the activities so they would take less time, and Eric expressed more confidence that students would “get what they need” from them. Eric instructed his students to do the laboratory activities early on in the series of classes, leaving the later classes time for lecture-based instruction.

What the Metaphors Constrained

For Eric, the source domains in both the jigsaw puzzle and fieldtrip metaphors hide aspects that do not map well to the target domain of teaching. This hidden quality arises because the imagery conjures or suggests some relationships but not others. An exemplary illustration lies in the history of genetics: Müller-Wille and Rheinberger (2012) demonstrated that “the lock and key principle … acted as an ‘epistemological obstacle’ to the molecularization of genetics…as its vivid imagery made it hard to adopt a different and new perspective” (p. 163). In the case of Eric, his teaching metaphors structured his perception of teaching and learning in such a way that they “hid” particular teaching tools. They were not appropriate, and so, Eric simply did not consider them.

The metaphoric lenses that shaped Eric’s view of knowledge and learning hid the amount of work that must take place in actual and meaningful communication (Reddy, 1979). During communication (teaching and learning), the brain filters, decodes, interprets, and categorizes incoming signs and signals (Kahneman, 2011). It does this unconsciously and automatically. To learn a novel concept, learners must draw from new experiences, if available, and then fix them to already existing experiences or portions of previous experiences in the mind. In so doing, they engage processes like thought experimentation, analogies, and visualization (Clément, 2008a; Nersessian, 2008; Carey, 2009). This is much more work (Reddy, 1979) than the “myth of objectivity” (objectivism) implies (Lakoff and Johnson, 1980); work which was obscured further by the metaphors Eric employed. The subjectivity that is part of meaning-making, and the role of student-student and teacher-student interactions in meaning-making had little place within the structure formed by Eric’s metaphors of the jigsaw puzzle and fieldtrip. These created epistemological obstacles that interfered with the type of teaching integral to the curriculum I had proposed.

The prescribed puzzle pieces and a well-trodden trail of Eric’s ready-made science prevent students from developing their own conceptions. They hide the notion that students’ final understandings were, in fact, personal. The jigsaw puzzle and fieldtrip metaphors and entailments hide the importance of such instructional tools as collaborative work among students and teacher and student personal model building. Students trying to negotiate meaning together might take (or make) an unpredicted path. Eric would need to anticipate such “forks in the road” and be there to mark the appropriate direction (Stein et al., 2009). His belief that meaning was 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, or negotiation of meaning. There was no worry they would take a different path. Meaning already existed, separate from the mind and 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. Further, students rarely answered questions posed by Eric. They focused their attention on the holder of the pieces or the leader of the fieldtrip and copied his words or writings carefully. They picked up the facts as he dropped them. He perceived this to be their need.

I contend, with this research, that it was Eric’s understanding of the nature of knowledge, his objectivism, reinforced by his experiences as a student and as a scientist, that guided his pedagogical decision making. By thinking knowledge has universal objective meaning and is not a personal construction, lecture was the only action that made sense. This was not a conscious decision by Eric, but an unconscious, or default, action based on his construction of reality. For in-depth treatment of the role of objectivism in science and education, I refer the curious reader to Appendix 3.

What about Using New Metaphors?

If these metaphors structured Eric’s reality, would it be possible to utilize a different metaphor or metaphors and structure a reality that affords more student-centered teaching practices? 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. Their participant changed from metaphors that gave her responsibility for student actions to ones emphasizing classroom director and observer. This changed how she viewed her relationship to her students. The participant no longer had to worry about controlling student behavior or making sure they learned exactly what she taught. She placed responsibility for learning with the students and became an observer of that learning. She began refocusing her energy on teaching, and students responded very well to the change.

As the puzzle master, or the fieldtrip leader, Eric had the authority and made it his responsibility that students learned exactly what he was teaching. Anything else would be “malpractice.” The most efficient way to accommodate that, accordingly, was through direct instruction. There is another element in geology education that would provide an experiential base different from Eric’s jigsaw puzzle and fieldtrip metaphors. Field camp (or field school) is a field-based course that is structured to have students map and interpret an area whose geological structure is unknown to them. Students canvas a given area, stopping in many different areas to collect data and interpret the geologic structure under their feet, based on its expression at the surface.

Typically, the role of the field camp instructors is to point out geologically significant locations to students and have them do the work of collecting and interpreting data. Could referring to teaching and learning in terms of a field camp metaphor and its entailments (collecting observations, integrating data,
visualizing structures, and synthesizing a map, etc.) shift the responsibility of student learning more toward the student, affording the instructor to “point out” aspects of significance but allowing students to derive that significance? The instructor would maintain much of her/his authority and would have responsibility of guiding them in productive directions, letting them struggle and maybe even fail as they create their own understandings. Through such an approach, students would come to know the terrain through personal trial and have the experience of generating their own knowledge.

“Teaching in the Making”

This paper started with a couple of assertions. First, the implementation of reformed curricula has a profound impact on student learning (Fairweather, 2008; Freeman et al., 2014). Second, reform-based curricular interventions are seldom implemented as designed (Hullerman and Cordray, 2009). Finally, teaching is a design activity (Brown, 2009) that, in addition to curricula, is also affected by such variables as teachers’ knowledge and perceptions, classroom settings, institutional structures, and culture (Markley et al., 2009). To facilitate the development (and implementation) of new curricula, it might help to draw a parallel to the development of new scientific knowledge.

Many have described the creation of novel scientific knowledge as an iterative process of generating a model, testing it, and then amending the model based on those results to enhance the model’s descriptive or explanatory power. This includes philosophers (Frodenman, 1995), cognitive scientists (Nersessian, 2008), historians of science (Giere, 1988), science education researchers (Clement, 2008a), as well as geologists (Oliver, 1991). The implication here is that the knowledge generation process for any one concept is never ending. Models, by definition, are never complete. There is always more to learn. Awareness of this process in the development of scientific knowledge is what Latour (1987) labeled “science-in-the-making.” In contrast, he saw “ready-made-science” as objectified scientific concepts in completed form—which is what is traditionally taught in science class. Indeed, science-in-the-making forms the foundation of the curriculum I wished Eric to implement.

Just as a considerable amount of communication and collaboration needs to take place to facilitate concepts-in-the-making, so a considerable amount of communication and collaboration needs to take place between those developing curriculum and those implementing it. Having the instructor be a part of the creative process of curriculum development ensures that factors influencing implementation, such as metaphorical structuring, are factored in or mitigated. Curricular development needs to be iterative; create a curriculum, implement (test) it, and modify it in light of results. I identify this process as “teaching-in-the-making.” I wanted Eric to implement a curriculum that I developed alone—“ready-made-teaching”—when I should have collaborated with him in an iterative process that allowed us both to communicate our ideals, buy-in, and ownership of the material. As with concepts, the curriculum is never “finished” but should ever be refined in a design-based research fashion (Brown, 1992; Collins, 1992).

**APPENDIX 1. PERTINENT RESEARCH ON TEACHERS’ BELIEFS AND PRACTICE**

Educational researchers have tried to understand teacher practice by discerning teachers’ beliefs about such concepts as teaching and learning, and the nature of knowledge (also referred to as epistemology), which are then related to observed teacher practices. An underlying assumption informs this research: “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 and Carter, 2007, p. 1076). Indeed, others have echoed this same sentiment.

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 [beliefs] appeared to foster the creation of more constructivist-oriented science learning environments (Tsai, 2006, p. 222).

“[E]ducators should pay more attention to teacher beliefs because these beliefs profoundly influence decision-making and teaching practices (Chen, 2008, p. 66).

Much work has been done, therefore, to determine the beliefs of teachers with the intent of modifying those beliefs to influence teacher practice.

Operationalizing someone’s beliefs has been an elusive task to date. In his review of teachers’ beliefs and practices literature, Mansour (2009) acknowledged the difficulty of defining this construct within the research literature. Jones and Carter (2007) gave a list of 11 different definitions of beliefs that appear in the science education literature. Given this diversity, it is not surprising that many approaches exist to discern teachers’ beliefs.

- Open- and closed-ended questionnaires (Aikenhead and Ryan, 1992; Lederman et al., 2002) and survey instruments (Chai et al., 2009; Kinchin et al., 2009; Eck and Stewart, 2010).
- Interview protocols (Richardson and Simmons, 1994; Luft and Roehrig, 2007).
- “Draw a Scientist” analyses (Minogue, 2010) where participants’ elicited drawings of a scientist are analyzed to determine their understanding of scientists.
- Written metaphors (Boukououts, 2000; Reeder et al., 2009).

While the latter two strategies here are less common, the overriding approach in all of these methods has been to identify beliefs by asking for participants to explicitly declare their beliefs. This research project differs from these prior approaches in that it develops an understanding of the instructor participant’s beliefs as implicit in his descriptions of experiences with teaching, learning, and the nature of knowledge.

That a person should hold beliefs about teaching, learning, and the nature of knowledge parallel each other seems intuitive. For instance, if someone thought that knowledge was objective and separate from the human mind—objectivism—(s)he would likely see teaching as the transfer of such information from the teacher (delivering a lecture) to the student (who receives it). Indeed, some researchers have reported evidence supporting such parallel beliefs in teachers (Tsai, 2002; Bryan, 2003) and school students (Tsai, 2006; A. Christodoulou et al., 2010, personal commun.). However, other researchers have described more complex interrelationships among beliefs. Kinchin et al. (2009) noted that graduate teaching assistants, who were teaching and conducting research in science, were “paradoxically, shepherded toward the language of constructivism whilst endeavouring to construct their personal understanding of their research problem” (p. 51, emphasis original). Bryan (2003) found that her teacher participant maintained two sets of conflicting beliefs. One set seemed to influence her traditional teaching, while the other guided her vision of constructivist teaching practices. Hodson (1993) found his teacher participant maintained substantial areas of confusion and uncertainty concerning, for instance, the role of scientific investigations in science teaching.

Drawing the relationship between espoused beliefs and teaching practice has been similarly complex, though a few investigations have demonstrated coherence between teacher beliefs and teaching practice (Brickhouse, 1990; Tsai, 2006; Ryker, 2014). Many more studies demonstrate a more complicated relationship (Hodson, 1993; Lederman, 1999; Tsai, 2002; Kang and Wallace, 2005; Chen, 2008; Markley et al., 2008; Jackson, 2009; Dolphin and Tillotson, 2015). Of note, many of the studies that show discrepancies between teacher beliefs and teacher practice have also invoked some kind of mediating circumstance in order to explain why, in their case, beliefs did not...
dictate practice. These include “knowledge structures” not being integrated, (Bartos and Leder-
(Schermpp et al., 1993), “conflicting beliefs” (Chen, 2008), the reward structure of the research un-
iversity (Markley et al., 2009), lack of empirical evidence of the effectiveness of active learning 
approaches (Day, 2012), and what Waters-Adams (2006) described as “tact beliefs”.

APPENDIX 2. ENSURING RELIABILITY AND VALIDITY OF RESULTS

Guba and Lincoln (1981) and Lincoln and Guba (1985) have advocated for the concept of “trustworthiness” with regard to qualitative research to ensure that the researcher’s reliability and validity, however, Morse and her colleagues (2002) have asserted that “the broad and abstract concepts of reliability and validity can be applied to all re-
search, because the goal of finding plausible and credible outcome explanations is central to all 
research” (p. 3). In this section, I will thus review how verification strategies help to verify and 
direct the research during its development … [including] investigator responsiveness, method-
ological coherence, theoretical sampling and sampling adequacy, and active analytic stance 
and saturation” (Morse et al., 2002, p. 9).

This project began as an investigation into student learning in the undergraduate geology classroom. However, I encountered an unanticipated circumstance: Eric did not implement the curriculum as we had discussed, which led me to change the focus of my research from student learning to Eric’s teaching. The investigation became a case study of instructor decision making in light of the contradiction between what Eric said he would do and what I actually observed him doing. I responded to these circumstances by refining the investigation and incorporat-
ing an embodied cognition theoretical framework after noticing the frequent use of metaphor 
later identified as the “jigsaw puzzle metaphor” and focused on metaphor use by Eric during his teaching and our discussions. As the data analysis got under way, I also identified the metaphor of student motion over the ground of knowledge, which I later characterized as the fieldtrip metaphor.

My methods for data gathering and analysis are consistent with the goals of the investigation. I wanted to understand Eric’s instructional decision-making motivations. This required gathering information about his beliefs about teaching, learning, and students, and how they might be reviewed. I audio-recorded all our mutual conversations dealing with the course, curriculum, and its implementation, and I observed and recorded his teaching. Because I was interested in Eric’s incidental use of metaphor, I never brought to his attention this focus. Doing so would have placed the reliability of these data in jeopardy (Morse et al., 2002), making him aware of the focus and self-conscious of his use of metaphor. To understand his beliefs, I am interpreting how Eric de-
scribed his own experiences, because personal experiences are “a central lens for understanding a person” (Creswell, 2008, p. 518) and a reflection of his structured reality. If, instead, I asked him explicitly about his beliefs, I would be asking him to do the interpretation, and I would not know the rules under which that interpretation took place.

My analysis of the data started early in the data collection process, as it became apparent that Eric’s implementation was quite divergent from my intended implementation. This timing facilitated an iterative approach to interpretation. It is this “iterative interaction between data and analysis [which] is the essence of attaining reliability and validity” (Morse et al., 2002, p. 12). My analysis went from emergent themes (Eric’s statements about science, the textbook, students, learning, teaching, the curriculum, and expressions of knowledge), to metaphor-based themes, and I began listing data in terms of primary metaphors and their entailments. About three quarters of the way through the data, I had identified eight primary metaphors, with four of them encompass-
ning the majority of the data, which I describe below. I noted several instances of metaphor use in the remaining transcripts, but no new categories emerged. This process, whereby no new coding categories form, is known as data saturation and “ensures replication in categories; replication verifies and ensures comprehension and completeness” (Morse et al., 2002, p. 12).

The results of the analysis describe Eric’s metaphorical structuring of his role, the role of his students, and the role of knowledge, and it consistently explains his actions. The explanation broadens and deepens (Thagard, 2012) our understanding of how the mind works. It broadens our understanding by extending embodied cognition beyond recent research on learning (Amin,
2015; Niebert and Gropengiesser, 2015; Dolphin and Benoit, 2016) into research on teaching. It also deepens our understanding by explaining metaphorical thinking (Nersessian, 2008) as a mecha-
nism for decision making.

I utilize a case study approach because it allows for the in-depth, exploratory investigation of some system (a person, a group, or a process) that is bounded or separate from other systems due to the nature of the case study having a single participant, my ability to gen-
eralize to a larger population is limited. However, as Taber (2003) stated with respect to his student participants, “studies that explore thinking in depth…go further than just identifying alternative 
conceptions or preferred mental models, but rather inform teachers about the learning process itself.” In other words, the investigation of teacher beliefs is not new, but investigation of teacher 
beliefs using an embodied cognition framework is further. This in-depth look into one instructor’s 
thought processes while teaching a new kind of curriculum may not inform us on how all instruc-
tors would think in a similar circumstance but can give us insight into areas that will be useful 
and important to investigate with other instructors.

APPENDIX 3. OBJECTIVISM IN BOTH SCIENCE AND EDUCATION

The idea that objects (including ideas) have intrinsic meaning that is separate from the mind 
and are therefore universally understandable (epistemological objectivism) underpins both the 
metaphors that structured Eric’s teaching. This is not surprising, in that objectivism plays a major 
role in both science and education. Considering the pervasiveness of the traditional style teaching 
(in both time and space), it is easy to understand that objectivism forms the foundation of how 
many instructors think learning happens (Sfard, 1998; Bartholomew et al., 2004). Berreiter (2002) 
identified the “mind as container” metaphor as a folk theory informing much educational decision 
making. This metaphor emphasizes the mind as a container into which we can put ideas. Similarly, 
Sfard (1998) identified 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). In 
fact, until just decades ago, it was common knowledge that students came to us as blank slates to 
be written on, or empty vessels to be filled (Freire, 1970). This idea resonates with such common 
language as, “delivering a lecture.”

These metaphors match Eric’s descriptions of “stuffing students full” of information, “build-
ing a mental foundation” and “preparing students” to be able to learn, and giving them “bits and pieces” of information. Lakoff and Johnson (1980) pointed out that the experiential basis of this metaphor comes from our receiving signs and 
signals through our senses, which our brain then translates into meaning. Books with cultural 
symbols (letters, words, and sentences) come into our possession, and sounds from a lecturer 
travel to us. When we read a book, or listen to a lecture, we feel we have learned. Because we are 
not conscious of the sense-making process, it seems as if we received that knowledge rather than 
having created it.

Giere (1988) demonstrated how objectivism is common in scientific research. He described 
constructive realism in his study of particle physicists in a proton accelerator lab. In the lab, physi-
cists worked on creating beams of protons and spoke of 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, because proton behavior is now 
so well tested and predictable, the physicists in the laboratory took for granted that protons with 
their prescribed characteristics are real objects that they can now use it as a tool for research. Giere 
said that it is important to understand that scientific knowledge is created, but it is also valuable 
to consider previous results as “real” in order to further investigation.

Being a scientist myself and studying such a well-tested theory as plate tectonics, I found it 
was easy to understand Eric’s objectivist stance while teaching about it. Like the protons in Giere’s 
(1988) study, plate tectonics is a well-established construction, developed from many areas of 
geoscience. 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…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 of as opposed to an 
explanation for observations: ready-made-science, as opposed to science-in-the-making. This 
statement mischaracterization of plate tectonics as a construct is common in many introductory text-
books (Plummer et al., 2007; Marshak, 2012; Reynolds et al., 2013) where authors point out, for 
instance, that the pattern of earthquake epicenters is such that they happen at plate boundaries. 
In reality, plate boundaries are constructions that rely on the patterns of earthquake epicenters for
their location. The boundaries are not the cause of the pattern but an explanation (a construction) for the observations of the pattern of seismicity. In our initial conversations about the intervention, I expressed my desire to record students building their own model to explain data given to 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” in my constructive realism (Giere, 1988) sense emphasized the personal nature of knowledge development; for Eric, it meant putting together universal facts to replicate universal truths. This was something very different indeed.

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