Section A

4. Abstract (1500)

Researchers are considering the role of conceptual metaphor use in science teaching and learning. Conceptual metaphor is giving meaning to an abstract concept (target) in terms of a more concrete concept (source), one developed from embodied experiences. Far from the traditional notion of literary adornments, metaphor is a tool in both generating and communicating knowledge. Characteristic of metaphors is that they highlight aspects of reality while hiding others. Experts are aware of what is highlighted and hidden taking it for granted when teaching or writing textbooks. Novices, who do not know which aspects they are supposed to consider or ignore, can interpret the metaphor in unintended ways, impeding learning. This project will analyze multiple introductory geology textbooks for their use of metaphor, both scientific (scientific language, e.g., tectonic plate) and deliberate (explicitly used for teaching, e.g., considering the mantle as flowing taffy). We aim to identify the more common metaphors used from book to book and determine if they relate to common misconceptions that students have in geology. If there are problematic metaphors, we will analyze them for their limitations (what each highlights and hides) and develop strategies to mitigate the difficulties. These strategies could range from instruction on the limitations of the metaphor to developing new metaphors. We would then try to measure effectiveness of the strategies for student learning. **(1482)**

Section B

1. Context (1500)

Dolphin & Benoit (2016) inquired how students learned about earthquakes. Using student conversations recorded during different lab activities, it became apparent that students were having difficulty conceptualizing the lithosphere of the earth as a whole unit with elastic behavior (the scientific consensus). Instead, they referred to the lithosphere as separate brittle pieces moving and colliding to create earthquakes. We hypothesized that it was the metaphor, "tectonic plate", that caused the difficulty in understanding. Metaphor use is pervasive in science, using aspects of a well-known concept (source) to give meaning to aspects of an abstract concept (target). In our study, lithosphere is an abstract concept. And, where novices hold no experiential meaning for tectonic, they do have many experiences with plates. Plates behave brittly, breaking when dropped. They are separate and can be pushed together causing collisions. In our study, students consistently referred to continents as plates; continents are only a part of larger tectonic plates. This is a common misconception (Francek, 2013), which could derive from their experiences with world maps showing only continents surrounded by ocean. The following year, we developed a new metaphor for lithosphere prior to teaching "tectonic plate". We used LITHOSPHERE IS THE SKIN OF THE EARTH. The skin is something that all students have experience with, its deformability, elasticity, and wholeness. **(1467)**

2. Teaching and learning context (1500)

Studies in conceptual metaphor are studies in experiential learning. Amin (2015) asserted the importance of research in this area for the advancement of science learning and teaching. According to conceptual metaphor theory, students develop understanding of an abstract concept (target) in terms of a familiar concept (source) derived though embodied experiences (Lakoff & Johnson, 1980). Cheek (2010) demonstrated that people develop alternative conceptions of geologic phenomena when the scales of time and space involved are out of the mesocosm–the range of everyday experience (Niebert & Gropengiesser, 2015). Also, objects of geologic study are often located underground or within rocks, impeding direct experience and making metaphor essential to learning. By identifying metaphors–deliberate and scientific–found in textbooks (Steen, 2007; Steen et al., 2010), analyzing them (Niebert & Gropengeisser, 2015), and correlating them with common misconceptions (Francek, 2013), we can determine what common experiences might be impeding learning (like *plate*, mentioned above), and what alternative experiences students could utilize to facilitate learning (like *skin*, mentioned above). Neibert et al. (2012) outlined a hierarchy of experiential learning strategies to this end: 1) enable experience in the target domain, 2) enable experience in a source domain (metaphor), 3) refer to an embodied source domain, and 4) reflect on embodied source domain (what is highlighted/hidden). **(1486)**

3. Scholarship around question (6000 characters)

In their groundbreaking work, Lakoff & Johnson (1980) demonstrated that metaphors are a pervasive and core aspect of communication, leading to the development of new areas of study such as cognitive linguistics (Ibáñez & Masegosa, 2014; Indurkhya, 1992) and embodied cognition (Clark, 2011; Shapiro, 2011). Following from this is the notion that metaphor is a foundational aspect in science progress and communication (Carey, 2009; Nersessian, 2008; Thagard, 2012). With terms like *greenhouse effect*, *DNA code*, *big bang*, *elastic waves*, *space-time fabric*, *elementary particles* (or *strings*) and *laws of nature*, it is obvious that metaphors are so ingrained in science as to be unrecognizable from normal, everyday speech. Metaphor enables scientists to reason about abstract phenomena, facilitating scientific progress (Beger & Smith, 2020). Once thought to be adornments to liven up text, we are coming to understand that our language is almost completely based in metaphor (Lakoff & Johnson, 1980, 1999). More important than their ubiquity in science are their cognitive effects (Steen, 2014).

Metaphors work by using aspects of something concretely familiar (source) to represent and give meaning to parallel aspects of an unfamiliar or abstract concept (target), a process called mapping. During mapping, the brain unconsciously and automatically invokes the experiences of the source, to prime or frame understanding of the target in terms of the source (Kahneman, 2011). For instance, Thibodeau & Boroditsky (2013) showed that people approached crime prevention depending on the metaphors used by media to portray crime. The participants in the study were more inclined to take an enforcement approach with the metaphor, CRIME IS A BEAST ATTACKING, and more likely to take a reform approach with the metaphor, CRIME IS A VIRUS INFECTING. Hauser & Schwarz (2019) also showed that the metaphor SURVIVING CANCER IS SURVIVING A BATTLE caused cancer patients to perceive cancer treatment as more difficult to endure and cancer was less controllable, potentially causing poorer health outcomes.

This same influence on perception appears in science as well. Allchin (2013, p. 140) described an example this way: "The *language* of 'laws of nature' is a metaphor that can powerfully shape thinking. That is, all of the familiar meanings of laws *in the human political realm* are transferred *to nature*" [emphasis original]. As a result, we view scientific laws not as *empirical descriptions* of natural phenomena, but as *controllers* of natural phenomena. Scientific metaphors are part of the language of science, and their effect has been documented in advancing science (Brown, 2020; Kuhn, 1993; Palma, 2018), but metaphor framing is also implicated in hindering scientific advancements. For instance, the PROTEIN AND SUBSTRATE IS LOCK AND KEY metaphor was so powerful that it inhibited the molecularization of genetics for decades (Müller-Wille & Rheinberger, 2012) and achieving true artificial intelligence will be impossible until researchers abandon the BRAIN IS A COMPUTER metaphor (Zarkadakis, 2015). Metaphor influences how teachers teach (Dolphin, 2016; Dolphin & Tillotson, 2015; Tobin & LaMaster, 1995), and how students learn (Dolphin & Benoit, 2016). Teaching invokes deliberate metaphors (Steen, 2014) to facilitate student learning of scientific concepts (Niebert & Gropengiesser, 2015; Niebert et al., 2012).

Purposeful use of conceptual metaphor to facilitate learning is receiving greater attention (Amin, 2015). Due to the large scale of most geologic phenomena (time and space) and the deliberate substituting of time with space (going down the rock record is going backward in time), the use of metaphors is an important tool for making these abstract phenomena concrete (Gómez-Moreno, 2020; Moore, 2014). Importantly, metaphors highlight and hide aspects of the concept they represent (Lakoff & Johnson, 1980). Experts are not immune from their misleading aspects and novices, who think differently than experts (Clement, 2008), can easily interpret the metaphors in unintended ways. This sets the stage for our project. Research into common geoscience misconceptions (Cheek, 2010; Francek, 2013) implicates students' lack of domain-related concrete experiences. Additional research indicates students' conceptions are seldom changed in lecture-based environments (Clark et al., 2011; Libarkin & Anderson, 2005; Wandersee et al., 2003). What different metaphors (deliberate and scientific) do introductory geology textbooks use? How do they correlate with common geological misconceptions? Dolphin & Benoit (2016) found that the scientific metaphor, *tectonic plate*, caused difficulty for students in understanding the nature of the lithosphere which impeded their conceptual development about earthquakes. How can we mitigate difficulties in student learning due to conceptual metaphors? Niebert & Gropengiesser (2015) developed a framework for external (experiential) representations to facilitate conceptual development. It includes 1) enabling experience in the target domain, 2) enabling experience in a source domain (metaphor), 3) referring to an embodied source domain, and 4) reflecting on embodied source domain (what is highlighted/hidden). For instance, Dolphin & Benoit (2016) proposed using marble tongs to demonstrate elastic behavior in rocks (Hubenthal, 2018) (number 1), giving students experience with a molecular model of a rock made with wooden balls and springs as the elastic bonds between atoms (number 2), and introducing the metaphor, *the lithosphere as the skin of the earth*, (number 3). The rationale was that students have concrete, embodied experience with their skin, and it highlights the properties of elasticity and wholeness (number 4) needed to understand earthquakes. **(5815)**

4. Scholarship around methods (6000)

Our first step in the project would be to familiarize RAs with the foundational literature on metaphor, cognitive linguistics, and embodied cognition. In essence, students will learn the theoretical mechanism for learning within this framework. They will develop understanding of conceptual metaphor theory (Lakoff & Johnson, 1980, 1999), cognitive schema development (Ibáñez & Masegosa, 2014), assimilation and projection (Indurkhya, 1992), and how metaphorical framing leads to a "cascade of associations" (Kahneman, 2011) or experiential gestalt (Lakoff & Johnson, 1999).

Once the RAs have become familiar with conceptual metaphor theory, they will learn how to identify metaphor in introductory geology and geophysics textbooks, which the co-PIs already have in their possession. Students will use the method put forth by Steen (2007) and Steen et al. (2010):

1. Examine word-by-word text, labeling parts of speech.
2. Mark metaphor related words (MRW)
   a. Use dictionary to compare the meaning of word in context to its most basic meaning– "a more concrete, specific, and human-oriented sense in contemporary language use…its historically older meaning" (Steen et al., 2010, p. 35).
   b. Flag as metaphor when there is a big enough difference between textual meaning and most basic meaning. We can consider the meanings distinct if the dictionary lists the two meanings under different numbered descriptions, or the word has a contextual meaning that differs from the dictionary meaning if only one meaning is given.
3. Identify cross-domain mapping. Identify mapping from words that would otherwise be incongruous to the context of the sentence. Look for forms of comparison from source to target. Do provisional mapping from source to target. Look for markers of comparison (e.g. like, as, more/less than, imagine, behave as if).

To date, there has been no systematic review of the metaphors used in geoscience textbooks. We are interested in identifying both scientific metaphor (e.g. *tectonic plate*, *layer cake stratigraphy*, *thin skin tectonics*, *continental drift*). They are the technical language of geoscience and have very defined meanings. However, with novices, the mapping (assigning certain aspects of the source concept to certain aspects of the target concept) may not take place as intended, therefore impeding meaningful learning for the student (Dolphin & Benoit, 2016). Due to the scale of time (Dodick & Orion, 2003, 2006) and space of many geological phenomena, and the use of space to describe time (Moore, 2014), geoscience instructors often use deliberate metaphors (Berger, 2016; Steen, 2014), those comparisons instructors purposely use for students to map the source domain to the target domain. This could include describing the lithosphere as the *skin of the earth*, the mantle as *a plastic* or *flowing taffy*, seismic waves as s*oundwaves*, fitting continents together like a *jigsaw puzzle*, as examples. Though the method Steen et al. (2010) proposed, outlined above, has the purpose to identify all linguistic metaphors, our project is most interested in the scientific and common, deliberate metaphors textbooks use to understand student conceptual development in response to exposure to these metaphors.

Geoscience educators have only recently begun to collect comprehensive data on students' geoscience conceptual development (Cheek, 2010). Results indicate there are many concepts spanning the domain of geoscience (Francek, 2013; Kirkby, 2014) where development seems impeded. This research has shown that much of the difficulty lies in the fact that many geological phenomena lie outside everyday experiences. The challenge is to connect these phenomena to the mesocosm.

Keeping this challenge in mind and understanding the importance of concrete experiences in meaning making, we will explore the nature of the problematic concepts to develop experience-based strategies for facilitating student conceptual development. Neibert & Gropengeisser (2015) asserted it takes metaphorical thinking to use experiences in the mesocosm for developing understanding in the microcosm or the macrocosm. For example, for the concept, *greenhouse effect*, the atmosphere is a part of the macrocosm. By using *greenhouse* as the source, the atmosphere essentially becomes a container bounded on all sides, where we can add CO_2, and can trap heat. People have experience with containers in the mesocosm, and so the abstract concept of global warming is grounded meaningfully in a very common embodied experience. Neibert et al. (2012) outlined a strategy for approaching teaching about abstract scientific concepts which included affording experiences in the target domain, affording experiences in a source domain (enabling metaphorical thinking), referring to a source domain, and reflecting on the source domain to determine what the metaphor highlights and hides. RAs will develop strategies following these steps for the problematic concepts.

Once we have developed new, experiential strategies for the teaching, we will have willing instructors teach the concepts using them. To understanding the efficacy of the new strategies, we will use questions from the Geoscience Concept Inventory (Clark et al., 2011; Libarkin & Geraghty Ward, 2011; Libarkin & Anderson, 2005) to measure pre- and post-instruction conceptual understanding. We will also conduct think-aloud interviews (Ericsson & Simon, 1993; Leighton, 2017) to develop a more nuanced understanding of how students are thinking about these concepts, especially after instruction. This will help us to see how students have assimilated the new instruction. **(5554)**

5. Engaging students (1500)
The critical analysis of metaphors will help students strengthen their own understanding of the concepts, and their understanding about how learning happens. They will make the connections between metaphor and student conceptual development. Then they will create their own teaching strategies where using their understanding of the problematic concepts and develop new mesocosm-scale experiences in which to engage students. Doing this successfully will require them to develop a more robust understanding of the concept. They will also practice communication skills by guiding instructors in the use and rationale of their novel approach. Student RAs will help present and publish findings, thereby closing the "gap" (Walkington, 2014) in the research cycle, and enhancing writing and communication skills.

For students experiencing the novel teaching strategies, our hope is that they, too, will develop a fuller, more robust understanding of the problematic concepts. Since part of the strategy will have a metacognitive aspect of reflecting on what the new metaphors highlight and hide about the target phenomena, we also project that students will become more aware of the nature of science (affordances and limitations for using models), as well as develop a deeper understanding for the process of learning which can help them in other learning environments (Georghiades, 2000). **(1386)**

6. How project will improve teaching and learning (3000)
Geoscience is seldom taught in any comprehensive way, K-12, in most countries (King, 2008, 2013). This means that when students come to an introductory class as an undergraduate, they have almost no experiences within the content domain, compared to other sciences which are taught starting in very early primary grades. Students develop many alternative conceptions about geologic phenomena, depending on personal experience, and these conceptions are very difficult to change, even as a result of direct instruction (Libarkin & Anderson, 2005; Libarkin et al., 2005; Schoon, 1995; Wandersee et al., 2003). The goal of our project is to first see if the way geology is being taught relates at all to some of the difficulties, and then to create novel experiential strategies that will lead to more effective instruction and more meaningful conceptual development for students. By incorporating a metacognitive piece with the strategies, we also afford students a better understanding of learning as a process that they can use in other classes (and life in general). For the student RAs, they will develop a much better sense of the learning process as well as a more robust understanding of the particular concepts of the novel strategies. You do not really know something until you must teach it to someone else.

Because the products of the project are knowledge creations (Bereiter & Paris, 2004; Paavola & Hakkarainen, 2005), sustainability is only reliant on communication of those products to willing instructors. We can easily accomplish this in the many venues available on campus and abroad. Within the Department of Geoscience, there are opportunities to present at multiple research symposiums and afternoon seminars. The Faculty of Science holds a regular Science Teaching Forum, where we could disseminate our findings across disciplines. Though the actual geologic metaphors may not be useful in other science domains, the method of discerning problematic metaphors and developing novel ones would still be useful. The Taylor Institute Annual Conference for Learning and Teaching will be a way to broaden our reach to the entire campus and beyond. We would also prepare presentations for international conferences such as the Geologic Society of America annual meeting and the National Association for Research in Science Teaching. We expect to be able to generate at least one publication from the findings. **(2423)**

7. Equity, Diversity and inclusion (1500)
This project will target equity, diversity, and inclusion (EDI) in two primary ways: 1) through seeking to hire a diverse group of RAs ideally capturing traditionally underrepresented groups, and 2) identifying use of metaphors in geoscience textbooks that may be culturally and/or gender biased. Use of language in standardized testing is known to contribute to lower performance of racially and linguistically diverse students (Ford, 2004). Shahram et al. (2017) indicate that incorrect or haphazard use of metaphor can also impede the communication of important concepts in health. This project will strive to make science accessible to all students (Beger & Smith, 2020). Specifically, target identification of metaphors in geoscience textbooks that may increase confusion for students from diverse backgrounds, including those for whom English is not their first language. We expect that working with a diverse group of RAs will catalyze our team's efforts to identify problematic use of metaphor in introductory geoscience textbooks. Specifically including EDI concepts as part of the metaphor identification framework will also help us to create broader connections between our work in geoscience and other fields such as health and standardized testing. **(1190)**

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