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Teaching Geoscience with a Pre-Analysis Step

A thesis submitted in partial satisfaction
of the requirements for the degree Master of Arts
in Education

by

Gary Benton Glesener

2016

ABSTRACT OF THE THESIS

Teaching Geoscience with a Pre-Analogy Step

by

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Master of Arts in Education

University of California, Los Angeles, 2015

Professor William A. Sandoval, Chair

The purpose of this study was to further develop and explore the use of an analogical teaching model I call The Pre-Analogy Step (PAS)—A teaching method to improve learners' familiarity of the important analogical features in a source analog prior to introducing an analogy for understanding a target domain. This study explores a sample of 24 students (13 boys, and 11 girls) and one teacher's use of the PAS in a combined third- and fourth-grade class as they participate in an instructional unit on plate tectonics. Interactional analysis using video and statistical analysis of a pre- and post-test were used to answer the following research questions: (1) do students' demonstrate an understanding of the source analog's relational structures during the PAS phases of instruction, (2) do students use relational structures of the source analog to reason about target concepts in plate tectonics, and (3) how do students' ideas about plate tectonics change throughout the unit? Students' understanding of the source analog's relational structure at a level of simple relations was indicated by their use of both verbal and gestural

modes of representation in their expressed models of the behavior of the source analog. The use of higher order relational structure was evident in addition to one case in which a student developed and used an analogical abstraction in order to reason between target models. Overall student performance between pre- and post-test results improved significantly with a 10% gain in mean difference ($n = 23, p < 0.05$). Improvements on plate tectonic specific items, in which students showed a 15% significant gain in mean difference ($n = 23, p < 0.005$) suggests that the educational unit had a positive influence on students' ideas about plate tectonics. Taken together as a whole, these findings suggest PAS may be a viable way to help students become more familiar with the relational structure needed to make inferences about the target models presented in this educational unit. Future research on PAS should take into account classroom variables, such as time and pressure, to allow researchers to gain a more explanatory picture of students expressed models.

The dissertation of Gary Benton Glesener is approved.

Noel D. Enyedy

Paul M. Davis

William A. Sandoval, Committee Chair

University of California Los Angeles

2016

TABLE OF CONTENTS

ABSTRACT OF THE THESIS	ii
TABLE OF CONTENTS.....	v
LIST OF FIGURES	vii
LIST OF TABLES	ix
ACKNOWLEDGEMENTS.....	x
INTRODUCTION	1
BACKGROUND	3
Analogies in the Science Classroom.....	3
The Strategic Approach to Teaching with Analogies	5
The Role of Familiarity in Analogical Reasoning	6
Children’s Conceptions of Plate Tectonics.....	7
Earth’s Structure	7
Earthquakes.....	9
Changing Alternative Conceptions.....	9
Framework for the Pre-Analysis Step (PAS).....	10
Phase-1: Assign an observational task (building the mental model)	10
Phase-2: Elicit students’ observations and assign new terminology (elicit students’ self- explanations	11
Phase-3: Understanding relational structure of the source analog.....	13
Phase-4: Review higher order relationships learned about the source.....	15
THE PRESENT STUDY	15
Methods	16
Settings and Participants	16
Instructional Context.....	16
Data sources and Procedures.....	23
Analytical Methods.....	25
FINDINGS.....	28
Research Question 1: Do students' demonstrate an understanding of the source analog's relational structures during the Pre-Analysis Step phase of instruction?.....	28
Transcribed Video.....	28
Research Question 2: Do students use relational structures of the source analog (foam) to reason about target concepts in plate tectonics?	30
Carry’s Understanding of the Role of Density in Plate Tectonics.....	30
Switching Representations Through Abstract Structure.....	35
Summary of Switching Representations Through Abstract Structure	39

Research Question 3: How do students' ideas about plate tectonics change throughout the unit?	39
DISCUSSION	40
Analogical Teaching Strategies and the Pre-Analogy Step	41
Student Understanding of the Source Analog During PAS	42
Students' Use of a Physical Analog Model	43
Accessing the Source Analog	45
How Students' Ideas About Plate Tectonics Changed Throughout the Unit	46
Limitations	47
Closing Remarks	47
APPENDIX A. Pre-/Post Test	49
APPENDIX B. Chart showing all answers chosen for test item 3 in both pre- and post-test.	57
REFERENCES	58

LIST OF FIGURES

Figure 1. A physical model and its target phenomena: (a) Elastic Rebound Strike-slip Fault Model (Glesener, 2009). The arrow highlights an analogous stream. (b) An image of the San Andreas Fault near the city of San Luis Obispo (USGS, 1999) with an arrow denoting an offset stream.....	5
Figure 2. Phases of the Pre-Analogy Step teaching model.....	10
Figure 3. One of the student group's worksheets from the foam activity in PAS phase-3.	20
Figure 4. Images from whole class discussion on day-3: a) representations of the foam model as described by students, along with corresponding vocabulary words; b) a list of the new vocabulary words.....	29
Figure 5. Sequence showing student's representation of the foam model while describing the definition of a spreading center: (1) hands on floor with fingers tips touching, (2) hands slid apart, (3) hand and arm placed in the center of the representation.	30
Figure 6. Ms. Kelly holding two pieces of foam: foam A (on the right) and foam B (on the left).	31
Figure 7. Carry's gesturing with her right fingers over her left fingers.	31
Figure 8. Carry grasps the end of the foam.....	32
Figure 9. Carry patting hand on foam A.	32
Figure 10. Marry pointing to foam B.....	33
Figure 11. Mary lifting foam A above foam B.	34
Figure 12. Ms. Kelly pushing down foam B and pulling up foam A.	34
Figure 13. Stacy (on left) pointing to the oceanic side of map figure.	35
Figure 14. John, Stacy, and Mary running the analog model with foam A and foam B.	36

Figure 15. Stacy making an s-pattern with her finger to emphasize the non-linear boundary on the map figure. 36

Figure 16. Stacy tries to contort the model in order to show her hypothesis..... 37

Figure 17. Stacy demonstrates her hypothesis using her knuckles as the plate boundary..... 37

Figure 18. Close-up of Stacy’s hands: sequence showing (1) initial position of seated knuckles and (2) final position of knuckles after being forced out of their seating. Arrows show direction of travel. 38

Figure 19. Image of Stacy slamming her hand onto the divergent plate boundary map. 38

LIST OF TABLES

Table 1. A general list of target models for the educational unit.....	21
Table 2. Summary of Daily Classroom Learning Activities.....	22
Table 3. Paired sample t-tests for pre-test vs. post-test scores (Categories: PT-Plate Tectonics, EI-Earth's Interior, EQ-Earthquakes, and OP-Other Processes)	40

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INTRODUCTION

Analogies are commonly used in both scientific practice and science education to understand and develop abstract ideas about natural phenomena. Though a highly successful teaching tool at times, the use of analogies in the science classroom does not always produce positive results (Blake, 2004; Bulgren, Deshler, Schumaker, & Lenz, 2000; Duit, 1991). There can be challenges to using analogies effectively. An acceptable way for teaching with analogies involves using a familiar, to the student, source analog to teach about a less familiar target concept (Harrison & Treagust, 1993). Though it may seem like an easy task, the measure of familiarity of common objects or situations from everyday experiences is often incorrect (Kamas & Reder, 1995). Low source analog familiarity is one of the primary challenges for using analogies effectively (Gentner & Gentner, 1983). This study addresses this key challenge to instruction.

Geoscience education provides an ideal subject area for the use of analogical teaching methods (see Gentner, Goldwater, & Jee, 2011; Jee, Uttal, Gentner, Manduca, Shipley, Tikoff, Ormand, & Sageman, 2010; Kastens & Rivet, 2010; Sibley, 2009). Many geoscience phenomena (i.e. Earthquakes, the formation of mountains, mantle convection and tectonic plate subduction) are temporally and/or spatially challenging to experience. Humans cannot observe the entirety of these kinds of phenomena with the naked eye. Their non-everyday/non-observable characteristics are considered to attribute to the difficulties students face when trying to learn their associated concepts (Ault, 1984; Dal, 2007; Gobert & Clement, 1999; Vosniadou & Brewer, 1992). Faced with these instructional challenges, geoscience educators must apply well-developed teaching methods for successful learning to take place. If a well-developed analogical

teaching approach is properly performed, students may be able to comprehend these abstract concepts by way of analogies.

The purpose of this study is to explore the use of an analogical teaching model developed in this work called The Pre-Analogy Step (PAS)—A teaching method aimed to improve learners' familiarity of the key analogical features in a source analog prior to introducing (or using) an analogy for understanding a target domain. The focus of this project is on using the PAS for overcoming the challenges of teaching with analogies. We employed interactional analysis on a video-recorded plate tectonics unit taught using the PAS. The study consisted of one teacher and 24 students (13 boys and 11 girls) in a combined third- and fourth-grade class. This work suggests using the PAS allows for a deeper view of analogical retrieval than what has been determined in previous studies on teaching with analogies. The findings from this work indicate that the efficacy of an analogical teaching approach can be improved when it is (1) designed to facilitate stronger familiarity of the source analog and (2) designed to facilitate proper mapping between the source and target analogs.

Students' source analog familiarity increases the efficacy of teaching with analogies. In the following sections I describe the theoretical basis for this new analogical teaching approach by summarizing the literature on the role of analogies in science education, familiarity in analogical reasoning, and children's ideas about spatially and temporally challenging concepts within the subject of plate tectonics. I then present the framework for Pre-Analogy Step. Finally, we describe the experiment and results derived from applying the PAS for teaching with analogies in the science classroom.

BACKGROUND

Analogies in the Science Classroom

In this study, an analogy is referred to as a comparison between two domains in which the relational structure within one domain can be used to understand the other domain by way of their similarities (Gentner, 1983; Holyoak, 2004). For example, one can make an analogy between a bolt of lightning and an Earthquake: estimating the distance to a lightning bolt is like estimating the distance to the focus of an Earthquake (Stamps & Smalley, 2006). The light wave from the lightning travels at a higher rate than the sound wave it produced, therefore the further a person is from the lightning, the more time it will take for the person to hear the thunder after the person sees the lightning. Similarly, the primary wave (a.k.a. p-wave) from an Earthquake travels at a higher rate than its secondary wave (a.k.a. s-wave), thus the further a person is from the focus of an Earthquake, the more time it will take for the person to feel the s-wave after the p-wave.

The most important part of any analogy is its relational structure (Gentner, 1983). Relational structure can be thought of as the set of relationships between objects in a domain, and the ways in which these relationships are situated within it. In the case of the lightning-Earthquake analogy, one relationship between the two different waves produced in each domain (lightning bolt and Earthquake) is that one wave “travels at a higher rate” than the other. This relationship is situated among a network of relationships (i.e. the relationship between the observer, phenomenon, and waves).

The learning benefits of using analogies to teach have been empirically supported. Analogies “may often be very useful for creating linkages within memory that would have an important influence on meaningful understanding, long-term retention, for transfer, problem

solving, and the skill of analogical reasoning” (Curtis & Reigeluth, 1983). Analogies can be used to gain conceptual understanding of new scientific concepts (Blake, 2004; Heywood & Parker, 2010; Mason, 1994), or restructure existing naïve notions (Brown & Clement, 1989; Joshua & Dupin, 1987; Mason, 1994; Stavy, 1991). Inferential reasoning skills, can be increased when students learn with analogies (Donnelly & McDaniel, 1993; Yanowitz, 2001).

Analogical reasoning can be very useful when learning about geoscience topics. Due to their scale alone, many geoscience phenomena (i.e., faults, Earthquakes, and tectonic plates) are difficult to impossible for students to experience firsthand. Instead, a physical analog model can be an alternative resource to help students reason about geoscience concepts (Kastens & Rivet, 2010). For example, Figure 1a shows a physical analog model, made from foam, wood, and threaded rods and nuts (Glesener, 2009), which can be used to explain why Earthquakes occur along the San Andreas fault zone (

Figure 1b) (USGS, 1999). The foam on the left side of the model moves in a parallel, but opposite, direction of the foam on the right side. This causes potential energy to build in the two pieces of foam. Similarly, the Pacific Plate (on the left side of the photo) travels in a parallel, but opposite, direction relative to the North American Plate (on the right), which also causes potential energy to build up in the two plates. Eventually the two sides slip in both situations, and potential energy is released as kinetic energy causing the foam and plates to move suddenly. This sudden release of energy along the San Andreas Fault produces an Earthquake.

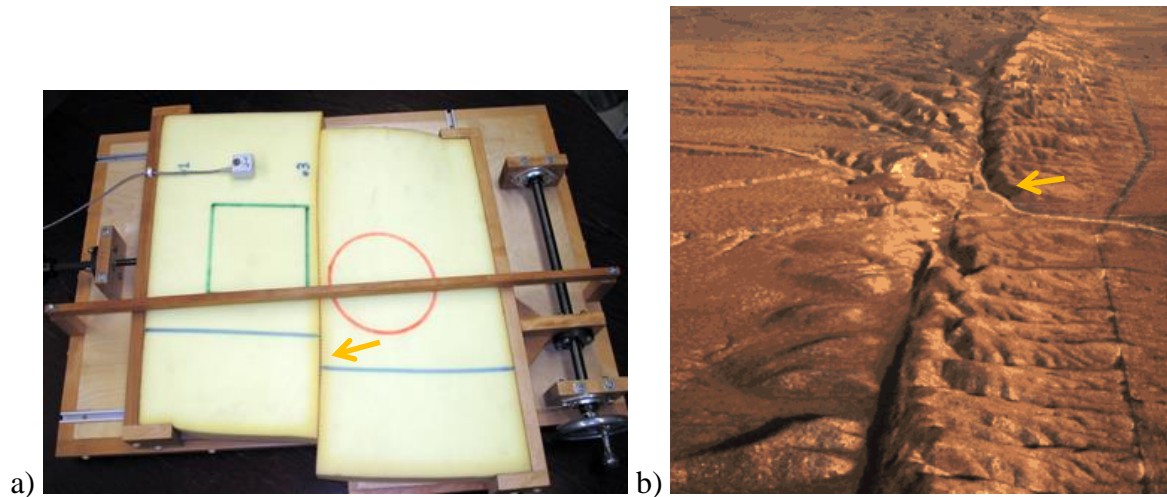


Figure 1. A physical model and its target phenomena: (a) Elastic Rebound Strike-slip Fault Model (Glesener, 2009). The arrow highlights an analogous stream. (b) An image of the San Andreas Fault near the city of San Luis Obispo (USGS, 1999) with an arrow denoting an offset stream.

The Strategic Approach to Teaching with Analogies

Though there is research supporting the use of analogies in teaching, research has also found there are many factors that may negatively influence a student's ability to learn from an analogy. Simply referring to an analogy during instruction may not be enough for the analogy to aid the student in developing understanding of the target. The effectiveness of teaching with analogies relies heavily on the approach taken by the teacher (Treagust, Duit, Joslin, & Lindauer, 1992).

Various strategies for teaching with analogies have been developed by researchers to increase student learning from analogies during instruction (Brown & Clement, 1989; Bulgren, Deshler, Schumaker, & Lenz, 2000; Dupin & Johsua, 1989; Else, Clement, & Rea-Ramirez, 2008; Glynn, 2007; Harrison & Treagust, 1993; Treagust, Harrison, & Venville, 1998; Zeitoun, 1984). The most widely used strategy found in the literature is the Teaching-with-Analogies (TWA) strategy by Glynn (1991), which is a set of procedures the teacher can perform during instruction to present the source and target in such a way that it will be easier for the students to

understand the analogy. Successful variations of Glynn's model have been implemented by other educational researchers (Harrison & Treagust, 1993).

The Role of Familiarity in Analogical Reasoning

Studies have shown that student familiarity of the source analog is an important part of an effective analogy (Braasch & Goldman, 2010; Schustack & Anderson, 1979; Wilbers & Duit, 2006). Gentner (1983) states that “an analogy is only useful to the extent that the desired relational structure is present in the person’s representation of the base domain” (p. 124) (a.k.a. the source analog). From subject’s low scores on qualitative comparison problems about the source analog, Gentner interprets the results of subjects’ failure to make correct inferences about target concepts as being due to poor knowledge of the source analog.

If familiarity is important to the effectiveness of an analogy, then why not choose a source analog that is highly common in the students’ lives? Though common phenomena in people’s everyday experiences may be more familiar than less common phenomena, there is a lot more than being common that makes something familiar. Nickerson & Adams (1979) examined college student’s abilities to recall the visual details of a common object—a penny. Their results showed poor performance in peoples’ abilities to recall a penny’s appearance in considerable detail. Nickerson and Adams speculated that memory of the features in common objects are limited to prior needs—to distinguish a penny from other U.S. coins, the distinguishing copper color of the penny is all one really needs. Similarly, other research has shown people’s lack of attention to the details of a wide range of everyday experiences (Castel, Vendetti, & Holyoak, 2012; Simons, 1996; Simons & Levin, 1998). If a common object is to be used as a source analog, but the relational structures of the object are inaccessible in the learner’s working

memory, then the mapping process would prove to be a difficult task, and the analogy may be lacking as an effective educational tool.

Source analog familiarity is important for effective learning with analogies; however, teachers must consider what may seem familiar to the learner because we cannot assume that its commonness will equal its familiar. Steps must be taken by the teacher to ensure the learner is familiar with important aspects of the source analog used in the mapping process.

Children's Conceptions of Plate Tectonics.

The aim of this section is to show that geophysical processes are challenging to learn. Research on children's conceptions about plate tectonics is relatively slim and new, stemming mainly from the 1990's forward (Orion, 2006; Reinfried & Schuler, 2009). The subject of plate tectonics encompasses a vast array of scientific concepts (i.e., Earthquakes, and Earth's structure) that are not clearly understood by many individuals within the general population (Francek, 2013; Libarkin & Anderson, 2005; Libarkin, Anderson, Dahl, Beilfuss, & Boone, 2005; Marques, Luis & Thompson, David 1997).

In order to gain an idea about the notions held by subjects in this study, the remainder of this background will focus on children within 1st through 5th grade. From empirical research, a variety of geoscience conceptual ideas held by children can be brought together for the purpose of seeing the richness of alternative conceptions children hold about plate tectonics. These studies provide ample evidence of the need for improving the teaching methodology of the temporally and spatially challenging concepts in plate tectonic theory.

Earth's Structure

Children have a variety of intuitions about the Earth's structure, including its shape, its features, and the processes by which those features are formed. These intuitions are often at odds

with scientific notions. Understanding the Earth's structure is an important part of understanding plate tectonics because plate tectonics is a system which is influenced greatly by how the parts of the Earth are situated and how they interact. For example, since the Earth's plates are much colder and denser than the mantle material below the plates, they have a tendency to sink in certain plate boundary conditions. To understand why the tectonic plates might be sinking, it is important to understand what exactly is below the plates allowing (or causing) it to sink.

The shape of the Earth

Understanding the shape of the Earth is essential to understanding tectonic plate interactions; however, studies have shown that many young children perceive the Earth as non-spheroidal (Baxter, 1995; Nussbaum & D., 1978; Nussbaum & Novak, 1976; Vosniadou & Brewer, 1992). Baxter (1995) analyzed students' (9- to 10-years-old, n=100) ideas about "easily observed" astronomical events from students' drawings of the Earth and found that about a third of the drawings presented the Earth as a flat saucer shape; about forty percent showed a round Earth with people living only in the northern hemisphere; and only about a quarter of the drawings illustrated a round Earth with people living all over.

The formation of landforms

Alternative conceptions about volcanoes and the processes that cause volcanoes to form are common among children (Ross & Shuell, 1993). Intuitive models of volcano formation have been observed across numerous studies (Gobert, 2000; Happs, 1982; Sharp, Mackintosh, & Seedhouse, 1995).

Earthquakes

Prior to formal instruction on Earthquakes, children can develop ideas about the causes of Earthquakes, as well as about the relationships between Earthquakes and volcanoes (Happs, 1982; Ross & Shuell, 1993; Sharp, Mackintosh, & Seedhouse, 1995). The most extensive studies on children's ideas about Earthquakes were done by Ross and Shuell (1990, 1993). Their studies suggest that about 75% of children in grades K-3 do not know what causes an Earthquake. In one study by Ross and Shuell (1993), about 40% of the students in grades 4-6, some of which claimed to have studied about Earthquakes during the current school year, thought that the Earth's core was the cause of an Earthquake, and about 20% claimed they did not know.

Changing Alternative Conceptions

There is clear evidence that children hold alternative conceptions scientific phenomena, which can be difficult to change (Chi, 2005; Chi & Roscoe, 2002; Driver & Erickson, 1983). To correct alternative conceptions about topics related to plate tectonics, some authors suggest that one of the few ways conceptual change can take place is by allowing students to see on their own the difference between their own preconception and the scientifically accepted concepts (Ault, 1984; Baxter, 1995; Dahl, Anderson, & Libarkin, 2005; Gobert & Clement, 1999; Marques, Luis & Thompson, David, 1997; Sharp, Mackintosh, & Seedhouse, 1995; Steer, Knight, Owens, & McConnell, 2005; Vosniadou & Brewer, 1992). The presence of these alternative conceptions after instruction indicates the strength of the students preconceived ideas. Finding a way to help students using analogical reasoning may be another way students can work through and check their own conceptions (Brown & Clement, 1989).

Framework for the Pre-Analogy Step (PAS)

The idea of PAS was originally sparked by anecdotal experience in trying to find a more constructive approach for teaching with physical analog models. The approach was designed to help students understand the fundamental physical properties in the model first, so the model could be used more efficiently for learning about the target concepts. The design had a stepwise/linear aspect so that it would be easier for a teacher to move systematically backward in the lesson to help identify areas where students might have had a difficult time following.

PAS can be implemented as a sequence of source analog enrichment phases—a sequence of phases to enrich students’ familiarity of the source analog. There are four phases to the PAS teaching model, summarized in Figure 2.

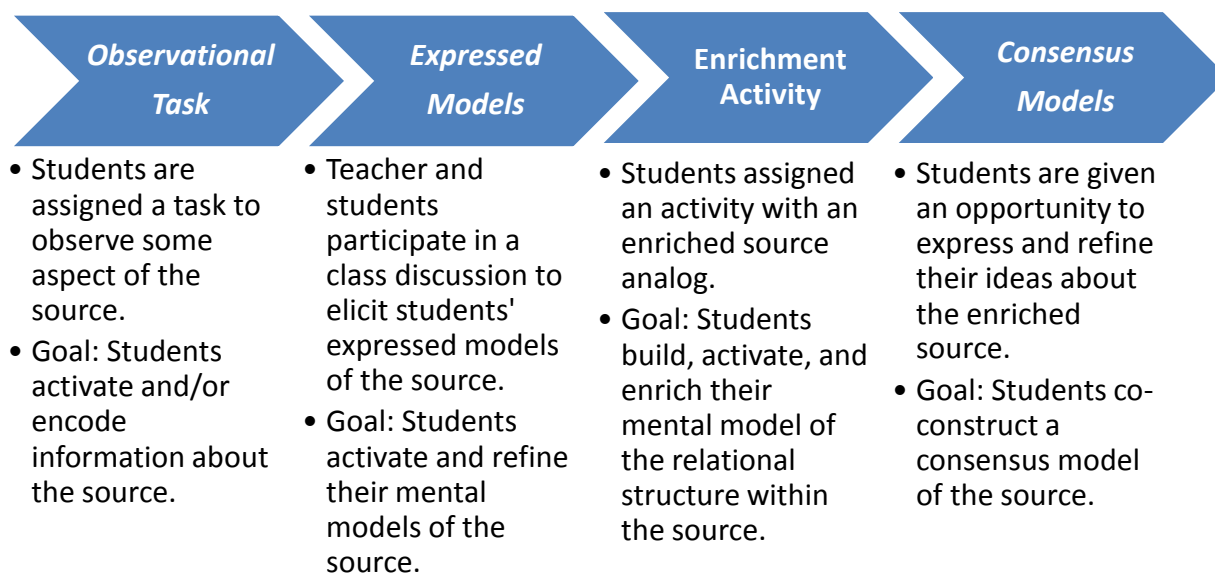


Figure 2. Phases of the Pre-Analogy Step teaching model.

Phase-1: Assign an observational task (building the mental model)

Prior to the formal classroom discussion on the target concept; an observational task is assigned to the students to help them become more familiar with the details of the source analog. The details of the source analog primarily include, but are not limited to, its relational structures

that are to be mapped onto the target concept during the analogical teaching lesson. The goal is for the students to develop new, and/or activate prior, memories of the relational structures to help strengthen it in long-term memory and be more easily accessible in working memory (Kamas & Reder, 1995).

As an example, let us consider foam rubber as a source for teaching about some of the properties of the Earth's crust. In the child's everyday interactions with the foam, there is likely no need for the child to have to understand the foam's physical characteristics (i.e., density, firmness, and elasticity); however, foam rubber may be abundant in the child's world (e.g., in toys, cushions, bathing products). By motivating the students through the observational task, the need is generated, which should increase the probability that the student will pay more attention to the important features of the foam. This perceptual shift is vital to reaching the analogy's full potential of being a highly effective tool for learning.

To save valuable classroom time, and since the second phase of the model involves students sharing their observations in a whole class discussion, an independent homework assignment is a good idea for phase-1. It is important that the students use their own perception to build their mental model of the foam so it can be activated again in memory and refined when participating in the phase-2, which is described below.

Phase-2: Elicit students' observations and assign new terminology (elicit students' self-explanations)

Activity Description

Phase-2 begins with a short whole-class discussion about the students' observations they made of the source during phase-1. The teacher has two main objectives in this phase. The first objective is to gather students' expressed models of the source, and determine what kinds of

student-shared ideas about the models may exist. Discovering students' meaning of their expressed models is an important part of this phase because it is from these meanings the teacher can introduce and connect terminology (i.e. mass and volume), which must be used to properly understand the target concept. The teacher must keep in mind that these expressed models are *student generated ideas*, and therefore, are likely *intermediate models*. The teacher must guide students' attention towards the learning objective so their intermediate models evolve to be more accurate.

During this phase, it is important for the teacher to guide the students toward the consensus models—"expressed models that have been developed, tested, and agreed among scientists or among groups of learners" (Gobert 2000 p. 892). It can be challenging to keep all students' ideas in the right direction, so if all the students agree, the students may help to keep each other's ideas from wandering too far off the correct path during discussion.

Revision of Mental Models

At this stage of the Pre-Analogy Step (PAS) the students who participated in the observational activity should have a developing mental model of the source analog. We now aim to develop a re-representation and redefinition of students shared ideas about the source. This is where the teacher-student co-construction manifests, and students' intermediate models—expressed models made up of both correct and incorrect ideas (Clement, 2008) and intuitive terminology begin their refinement toward the target models. The teacher attempts to match any incorrect student-generated terminology with the correct scientific terminology that the students must learn in order for mapping the source onto the target, and then continues the discussion using revoicing techniques (O'Connor & Michaels, 1993) until students begin to use the new terminology more frequently and spontaneously. For example, if a student uses the term weight

when he/she should have used the term mass, this would be the teacher's cue to introduce the term mass and address the difference in meaning between the two terms. As the discussion of the source analog continues, if a student uses weight again when mass was the appropriate term, the teacher could repeat what the student said, but with the word mass in place of weight.

Explicitly aligning the scientific terminology with the student generated terms (e.g. by writing the terms side by side on chalkboard) may ease the process in adopting the scientific terms into their vocabulary.

Forms of Expressed Models (Modes of Representation)

The teacher must also be aware that students' expressed models may come in various modes of representation (i.e., verbal, pictorial, and/or gestural) (Boulter & Buckley, 2000). If a student using both verbal and gestural representations in their expressed model, but one of these modes (e.g. the gestures) seems to be communicating incorrect ideas, then it would be wise to assess the student's understanding by having the student elaborate a bit more on their ideas. If the student's ideas are correct, then re-gesturing (similar to revoicing) for the student may improve the student's gesturing, as well as help other students gain a clearer picture of what is being communicated. If the student's ideas were incorrect, then guided questioning may be used to help the student correct their ideas so the new terminology is well adopted.

Phase-3: Understanding relational structure of the source analog

This phase provides the opportunity to introduce the higher-order relationships in the source analog, which is the most important part of an analogy (Gentner, 1983; Gentner & Smith, 2012). Some analogies may be more complex than other analogies simply due to having greater levels of relational structure. For example, the Elastic Rebound Strike-Slip (ERS) Fault Model (see Figure 1a) is a physical analog model that uses two different human-driven dynamic

mechanisms to produce normal and shear forces, which provide a static frictional force between two foam blocks. The stress increases between the two pieces of foam. Eventually, when it is greater than the static friction, it causes the blocks of foam to slip past each other and produce the elastic rebound phenomena.

The analogies that can be expressed from this analog model are: (1) the elastic properties of the foam blocks are like the elastic properties of the tectonic plates in the target system; and (2) the normal and shear force mechanisms are similar to the target's normal and shear force mechanisms that apply force to the Earth's plates. Although the common relational structure should afford greater learning potential, many young learners may find it challenging to process a great number of details at once (Gentner, 1988, 1989). This challenge is the basis for phase-3.

In phase-3, students work on a classroom activity in which the students are to gain experience using some of their new terminology from phase-2 by applying the terms to the materials that will become individual source analogs. One example of an individual source analog to help students with the ERS Fault Model would be friction blocks. A teacher could have the students slide various materials together and record their observations of what happens to the materials. The students then could describe the varying amounts and directions of forces used, as well as the characteristic behaviors of the materials from the effects of the force. If foam blocks are used, then students might use terms similar to bending or squeezing to describe some of the effects on the foam. This phase is intended to reduce students' cognitive load by strengthening long-term memory for the new terminology as well as activate other ideas students may have about the source domain that may not have been activated during the previous phases. A similar approach is the Bridging Analogies teaching model (Brown & Clement, 1989), where the analogy is expressed in different ways to help the learner identify analogous features that may be overlooked when presented with the comprehensive form.

Phase-4: Review higher order relationships learned about the source

Phase-4 follows much like phase-2 in that it involves a whole-class discussion to review some of the students' observations made in the previous phases, and a chance to introduce new terminology that students still have not covered in describing the source analog. In contrast to phase-2, phase-4 focuses heavily on understanding the higher-order relational structure in the source analog as opposed to its object attributes. This is where the teacher-student co-constructed consensus model should take its largest leap in becoming a highly familiar source domain because the relational structure is vital for reasoning with analogies (Gentner & Gentner, 1983; Gentner & Smith, 2012; Holyoak, 2012).

Through a collective discussion, the teacher and students review the activities, terminology, and observations from the previous phases. The teacher mostly elicits student expressed models describing causal relationships. The students will be more likely to map commonalities between the source and target analogs if they are well familiar with the higher-order relational structure (Gentner & Toupin, 1986).

This phase is complete once the students can demonstrate they are familiar with the relational structure of the source analog. The teacher should be able to observe students discussing relational structure of the source analog using the terminology introduced in phases 2 and 4.

THE PRESENT STUDY

The purpose of this study is to further develop and explore the use of an analogical teaching model I call The Pre-Analogy Step (PAS)—A teaching method to improve learners' familiarity of the important analogical features in a source analog prior to introducing (or using) an analogy for understanding a target domain. This study explores a sample of 24 students (13

boys, and 11 girls) and one teacher's use of the PAS in a combined third- and fourth-grade class as they participate in an instructional unit on plate tectonics implemented by one teacher.

Interactional analysis using video and statistical analysis of a pre- and post-test are used to answer the following research questions:

- (1) Do students' demonstrate an understanding of the source analog's relational structures during the Pre-Analogy Step phase of instruction?
- (2) Do students use relational structures of the source analog (foam) to reason about target concepts in plate tectonics?
- (3) How do students' ideas about plate tectonics change throughout the unit?

Methods

Settings and Participants

This study was conducted with a sample of 24 students (13 boys, and 11 girls) in a combined third- and fourth-grade class as they participate in an instructional unit on plate tectonics implemented by one teacher (Ms. Kelly) during the Spring of 2010. The students were selected from a preK-8 school located in a major metropolitan area of southern California. The school's demographics at the time was 20% Latino, 12% Latino-Caucasian, 7% African-American, 3% African-Caucasian, 9% Asian, 5% Asian-Caucasian, 36% Caucasian, and 8% other.

Instructional Context

In Spring of 2010, I assisted in the design of an instructional unit on plate tectonics that was part of a larger educational research project already in progress. The unit was implemented over 7 weeks, approximately 2 days per week, 2 hours per day. In this unit students learned about

the three main types of plate boundaries (convergent, divergent, and transform) through various inquiry activities. The activities incorporated physical analog models from which students were to draw analogies about the plate boundaries.

The Pre-Analogy Step in this Unit:

Following the model outlined above, I designed a PAS sequence for this unit. Foam was chosen as the source analog to support learning about the target concepts in plate tectonics. Here I describe the PAS sequence specific to this study:

Phase-I: Assign an observational task

Prior to the formal classroom discussion on plate tectonics, an observational homework task was assigned to the students. Specifically, the students were asked to make some observations about the various kinds of foam around the house, and to take notes on these observations because they may be useful during their next classroom discussion.

In these students' everyday interactions with the foam, there is likely not much of a need to understand the analogically important relational structure of the foam, in this case, the physical characteristics of the foam (i.e., density, firmness, and elasticity of the foam). The need is created by motivating the students through the assignment and potential discussion that follows. The students' knowledge accessed and/or gathered about the foam during this phase served as the datum in the proposed teaching approach. From this datum, knowledge of the source analog was to be constructed and refined in the following phase till it became a useful understanding.

Phase-2: Elicit students' observations and assign some new terminology

Phase-2 began with a short whole-class discussion about the students' observations of the foam. There were two main goals of this phase: (1) to find out what observations the students made during the observational task, and establish a consensus model of the foam based on these ideas; and (2) to build a new representation of the shared ideas—from being represented by intuitive terminology (i.e. weight) to being represented by scientific terminology (i.e. mass).

First, it is important to elicit students' intuitive representational terminology of the foam because “students use language associated with their past experience to explain or otherwise describe unfamiliar or novel phenomena” (Flick, 1991). This phase affords many opportunities for the students to build-on and refine their intuitive ideas. The discussion is intended to motivate the students to access their mental models of foam and create expressed models in the verbal form. Students have the opportunity here to listen to other students' verbal models, which in turn could be used to make refinements of their own. If the students disagree about others expressed models of the characteristics of the foam, their understanding of the foam may be further enhanced through argumentation.

For the teacher, the primary objective here was to guide the students toward a shared understanding about the foam whether or not the correct scientific terminology is expressed by the students.

The second part of this phase involved matching the student intuitive terminology used in their expressed models with the correct scientific terminology that the students must use later to properly map the source onto the target. If the teacher noticed the students beginning to share similar ideas about the foam, as observed from increased spontaneity of the students talk, the scientific terminology can be introduced. Explicitly aligning the scientific terminology with the

student generated terms may ease the process in adopting the scientific terms into their vocabulary.

Phase-3: Understanding relational structure of the potential source analog

Phase-3 began after the students had been introduced to the correct scientific terminology used to describe the characteristics of the foam. This phase was intended to give students a chance to practice the new terms as they participate in a classroom activity to make salient the relational structure in the source analog.

In this activity, students made observations while manipulating two pieces of foam in ways similar to ways tectonic plates interact at various plate boundary types (i.e., convergent, divergent, and transform boundaries). The students were directed to describe the foam in terms of the foam so the focus could be on what is important in this phase—understanding the relational structure of the source analog. Each group recorded their observations on a worksheet (Figure 3).

Name: _____ Date: 4/20/10

Observe each piece of foam carefully and write down three attributes to describe it.

4

Foam A (white)			
Foam B (yellow)			
Foam C			

Foam pieces	Move the foam pieces so that they interact in the ways the arrows show. Then answer the questions for each interaction.		
	⇒⇐	⇔	↑↓
AA What did you do? What happened? Why did that happen?	when we pushed A and A together, they both went up. 	when we pulled A and A apart, they make a space. 	the two pieces of foam rub against each other.
AB What did you do? What happened? Why did that happen?	When we push A on B, A goes up. I think it is because B makes more pressure. 	when we pulled A and B apart they make a space. 	When they rub A goes up.
BB What did you do? What happened? Why did that happen?	one piece of foam mounts after a while. 	when we pulled B and B apart, they make a space. 	when they rub against each other it comes. B and B were not that easy to push as A and A.

Figure 3. One of the student group's worksheets from the foam activity in PAS phase-3.

Phase-4: Review higher order relationships learned about the potential source

Just as in phase-2, phase-4 involves a whole-class discussion to review some of the students' observations made during the classroom exercise, as well an opportunity for the teacher to ingrain the scientific terminology and introduce new ones into the students' vocabulary. At the completion of phase-4 of the pre-analogy step, the instructional unit moved on to introduce the topic of Earthquakes and pose the questions of where the most powerful Earthquakes in the world occur, and what produces them.

Table 1.

A general list of target models for the educational unit.

Target Models for this unit:

- Tectonic plates are a part of the Earth.
 - Earth's surface is a part of its tectonic plates.
 - There are two kinds of crusts in these plates: Continental and Oceanic.
 - Oceanic crust is denser than continental crust.
 - The area where two plates meet is called a boundary.
 - There are three types of plate boundaries: Convergent, Divergent, and Transform.
 - Pressure causes the plates to slide past each other.
 - Friction is a force between the plates that makes it difficult for the plates to slide past each other.
 - Tectonic plates have elastic characteristics
 - An Earthquake occurs when two plates slide by each other
-

Daily Classroom Learning Activities:

With the exception to the first phase of the Pre-Analogy Step, students worked on classroom assignments in triad groups. Whole-class discussions were held daily with students sitting at desks or sitting on the ground in a circular area. Table 2 outlines the daily classroom activities in this unit.

Table 2.
Summary of Daily Classroom Learning Activities

Week	Day	Summary of Daily Classroom Learning Activities
0	0	<u>PAS Phase-1</u> : Students are given a homework assignment instructing them to make observations of various types of foam they have around their living environment.
1	1	Whole-class Discussion: teacher and students discuss what the students know about plate tectonics. PAS Phase-2: the teacher and students discuss what the students know about the properties of foam. PAS Phase-3: Foam Activity.
	2	PAS Phase-3: Foam Activity.
2	3	PAS Phase-4: Assign new vocabulary to student generated vocabulary. Demonstration of Elastic Rebound Strike-slip (ERS) Fault Model.
	4	A review of new vocabulary. Discussion about density. Location of plates in Earth's interior. Demonstration of Convection Model.
3	5	Labeling the plate boundaries on the vector map.
4	6	Paper Plates: Plate simulations with paper cutouts. Students record their findings on a matrix worksheet.
	7	Discussion of models and their purpose. Paper Plates: Plate simulations with paper cutouts. Students record their inferences on a matrix worksheet.
5	8	Whole-class Discussion Students explain their inferences about what is happening at specific plate boundaries.
	9	Whole-class Discussion Students share their ideas about what boundary regions create the greatest amount of pressure. Students reconvene in small groups and discuss their ideas before going back to a whole-class discussion.
6	10	Whole-class Discussion. Students share their ideas about what boundary regions create the greatest amount of pressure.
	11	Exploring Earthquake Data: From data packets distributed to the groups, each group must decide what type of plate boundary is likely to cause the strongest Earthquakes.
7	12	Student Presentations Students evaluate posters that were made by each group about what type of plate boundary is likely to cause the strongest Earthquakes.
	13	Continuation of previous day.

Foam Analog Models Used in This Study

The foam analog models were used by the students to simulate aspects of three kinds of plate boundaries: convergent, divergent, and transform. There were four foam blocks in total for each group. Two blocks were less dense than the other two. The less dense blocks represented tectonic plates consisting of continental crust, and the denser blocks were used to represent plates with oceanic crust. The approximate size of each block was 2” thick, 12” wide, and 24” long.

Data sources and Procedures

To discover if the Pre-Analogy Step could be a viable teaching method for enhancing students’ source analog familiarity, three primary data sources were used: (1) transcribed video recordings of students participating in small (triad) group and whole class work, (2) students' writing and drawings worksheets during small group activities, and (3) items from a modified concept inventory exam on geoscience concepts administered as a pre- and post-test (see APPENDIX A).

Video Data Collection

Video data was collected over a 7-week period. Aside from the third week, 2 days per week were filmed. Each day was approximately 1-2 hours of data and consisted of both whole class and small group inquiry exercises, instruction, and discussions. Only one small group was recorded per day. Groups were selected on a rotating basis, such that every group was recorded every 5-6 lessons.

Content logs were made by the research team for each day video data was collected. Content listings in each log were indexed by time and categorized as whole class or small group activity. An additional category was used for instructor interventions.

Challenges to data collection

There were many instances where the video was inaudible, due to too much noise in the room, a misdirected microphone, or disturbance of the microphone by the students or videographer. In addition, the use of only one camera made it challenging to collect video from all of the available groups during small group activities. Still images were taken of classroom materials and whiteboard text/drawings in order to capture these artifacts in more detail.

Pre-/post-test

Students were given a concept test prior to, and at the end of the educational unit. Both tests were exactly the same. Questions on the pre-/post-test had been modified from the Geoscience Concept Inventory (GCI) (Libarkin & S.W., 2008), version 2.1.1. Since the GCI was originally developed for college students, the language in the questions were simplified to make them comprehensible to the third and fourth graders.

There were a total of 16 multiple choice questions mostly covering related topics in plate tectonics: Earthquakes (3), Earth's internal structure (3), and general plate tectonics (7). The three remaining questions touched on other processes in the Earth, such as the rock cycle, age of mountains, and ocean waves.

Procedure

The pre-test was administered in the classroom to all the students at the same time, one day prior to the educational unit on plate tectonics. When the students finished the test, the tests were collected. The students never saw the questions again until the post-test was administered at the end of the session on the last day of the educational unit.

Classroom Materials

In addition to the foam activity worksheets (Figure 3) described in the Instructional Context section above, students labeled the types of plates on a map, participated in another activity called Paper Plates in which they were asked to make certain predictions about the tectonic plates based on how the plates were moving and the knowledge they gathered from the foam activity.

Analytical Methods

Research Question 1: Do students' demonstrate an understanding of the source analog's relational structures during the Pre-Analogy Step phase of instruction?

To find out if and how students demonstrate an understanding of the source analog's relational structures during the Pre-Analogy Step phase of instruction? Content listings from the video content logs were used to locate key segments of video where groups of students talk to each other while discussing or interacting with the source analog during days 1-4. All of these video segments were observed, codified, and transcribed if applicable (except video from day 1). In the initial coding phase, students expressed attributes of the foam and analog model were identified with students, groups, and context.

After initial coding, I coded students' expressed models using Boulter and Buckley's (2000) "Typology of Expressed Models" (p. 49). The typology crosses "modes of representation" (i.e. concrete, verbal, or gestural) with "attributes of representation" (i.e. static or dynamic behavior). To highlight the types, I used single modes and grouped them according to the referent.

Based on students expressed models, aspects of the foam and physical analog model using Buckley and Boulter's (2000) analytical framework for understanding representations and

expressed models. Aspects of the foam analog model expressed by the students were coded into three categories: structure, behavior, and mechanism. Object attributes, such as size, shape, and the foam itself, belong to the structure category. The behavior category consisted of “dynamic changes in the entity” (p. 124) (e.g. ‘the foam moved up’). Expressed models describing interactions (or causal relationships) between parts of the analog model fell under the category of mechanism.

Since the analog model consisted of nine combinations (see Figure 3), differing in structure (e.g. foam type) and/or behavior (e.g. push together, pull apart, and side-by-side), each combination received a different code in order to identify any relationships between the limitations and affordances of the analog model and students’ expressed models of a particular plate boundary.

Coding Classroom Materials: Content from the activity sheets followed the same coding scheme as the video coding. Content from the attribute section was primarily coded under structure, and the foam interactions content varied across structure, behavior, and mechanism. While coding these attributes, some of the students’ ideas about plate tectonics became apparent. Though students were instructed to write down their observations of the foam, many used previously learned plate tectonics terminology. These artifacts were also coded under “ideas about plate tectonics.”

Analysis for Research Question 1

The deconstructed expressed models were compared with the foam analog model. First, I looked to see if there were missing structural aspects in the expressed models. Modes were combined to gain a clearer image when a mode was incomplete or ambiguous. For example, if a verbal model used the word ‘thing,’ then a gestural model would be looked at to verify what “thing” was referring to in the verbal model. Many non-gestural models (i.e. pointing), and other

external artifacts in the students' space (i.e. maps on the wall), were also used to determine the meaning of an expressed model.

If there was a close match between structural aspects of the expressed model and the foam analog model, a comparison was then made at the order of behavior and mechanism. This is where relational structure is described. Behavior consisted of simple relationships (e.g. foam-A moved over foam-B), and mechanism consisted of more causal relationships (e.g. the pressure on foam-A cause foam-A to bend). These kinds of expressed models are demonstrations of an understanding of the source analog's relational structures, which was developed during the Pre-Analogy Step phase of instruction?

Research Question 2: Do students use relational structures of the source analog (foam) to reason about target concepts in plate tectonics?

Coding Video

I used the initial coding scheme in the analysis for research question 1 to code for question 2. Content listings from the video content logs were used to locate key segments of video in which students mention the aspects of the foam while trying to understand some aspect of plate tectonics during days 4-7. All of these video segments were observed, codified, and transcribed if applicable. In the initial coding phase, students expressed models of the foam and analog model were identified with students, groups, and context.

Research Question 3: How do students' ideas about plate tectonics change throughout the unit?

To find if students' ideas about Earthquakes and plate tectonics changed through the unit, the pre-/post-test was analyzed using a one-tailed paired t-test. The pre-/post-test was categorized into four major topics: Earthquakes (items 3, 11, 12), Earth's interior (items 2, 5, 6), general plate tectonics (items 1, 4, 10, 13-16), and other Earth processes (items 7, 8, 9). These categories

were compared to see if students' understanding of the concepts increased over the course of the classroom unit.

For a test items 3, 6, 7, and 11, students were told they can circle more than one option for their answer. If an incorrect option was chosen, in addition to a correct option, then the item was scored as incorrect.

FINDINGS

Research Question 1: Do students' demonstrate an understanding of the source analog's relational structures during the Pre-Analogy Step phase of instruction?

According to the literature, familiarity of the relational structure of the source analog is a key factor in the learner's ability to effectively learn from an analogy. Therefore, this research sought to answer the question: Do students' demonstrate an understanding of the source analog's relational structures during the Pre-Analogy Step phase of instruction? Students' ability to express higher order relations about the source analog (foam in this study) indicates they have adequate familiarity with the source to apply it to the target.

Transcribed Video

Video of students engaged in whole class and/or small group discussion was analyzed to find students expressed models of the source analog. Specifically, the analysis was intended to find episodes in which students discussed the relational structure of the source analog.

Reconstruction of the Foam Analog Model

On day-4 of the instructional unit, Ms. Kelly met with the class to review the vocabulary, which was introduced to them on day-3. The vocabulary was made available to the students on

poster paper at the front of the room (Figure 4). Ms. Kelly called on various students to describe what these words mean.

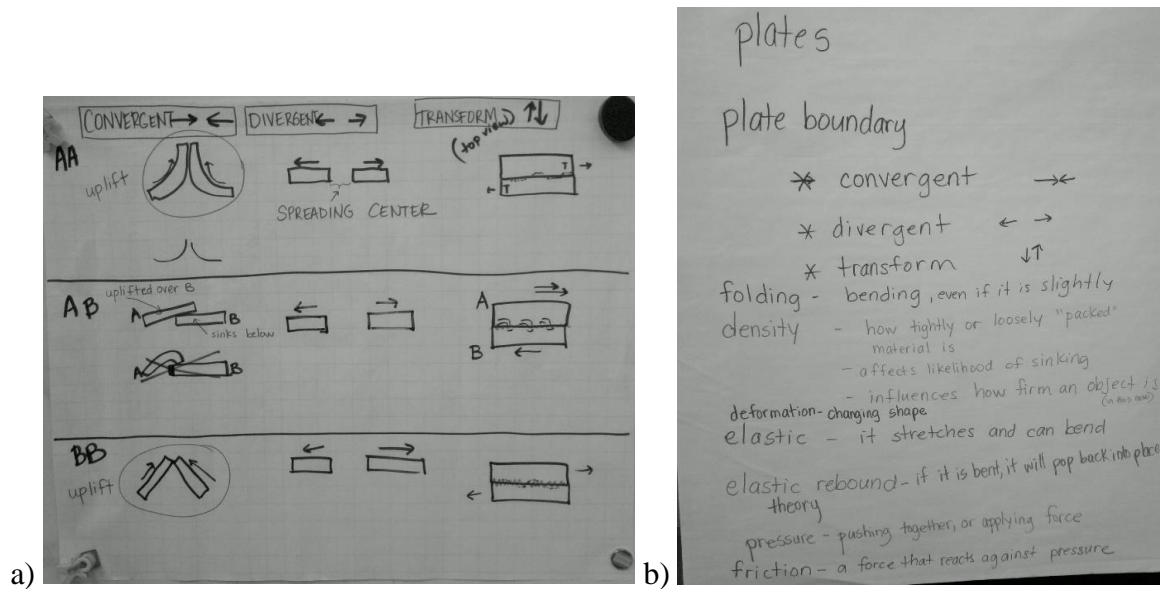


Figure 4. Images from whole class discussion on day-3: a) representations¹ of the foam model as described by students, along with corresponding vocabulary words; b) a list of the new vocabulary words.

The vignette below, along with images in Figure 5, are an example of how some students responded to Ms. Kelly's questions.

Ms. Kelly: We learned another piece of information that goes along with a divergent plate boundary..right? We learned another type of vocabulary...another vocabulary word. Let's see...uuuum...Anthony.

John: spreading center

Ms. Kelly: Yes, what is a spreading center (inaudible)

John: so...so...[places palms of hands on floor with finger tips facing each other] when the two pieces of foam moves [slides hands away from each other] in the middle is a spreading center where they spread out

¹ Many limitations of the foam model were addressed for each of the different plate boundary types throughout the educational unit during whole class discussions. The distance between the two foam pieces in the divergent cases gave the opportunity for the teacher to ask what they thought would fill in the gap, and students were made aware of the thickness of the crust for the AA-convergent case during discussion. One case in particular, BB-Convergent, may have been missed. In retrospect, running the model on two tables separated by a couple feet would have likely prevented the two pieces of foam from producing the A-shape seen in the bottom left corner of Figure 4a.



(1)

(2)

(3)

Figure 5. Sequence showing student's representation of the foam model while describing the definition of a spreading center: (1) hands on floor with fingers tips touching, (2) hands slid apart, (3) hand and arm placed in the center of the representation.

The vignette above shows John's expressed model of a spreading center. John used verbal and gesture modes to represent the structure and the behavior of the foam analog model. Once the expressed model of the foam analog model was about finished, John connected the concept of the spreading center by gesturing where the spreading center is located in the model and saying "in the middle is a spreading center where they spread out" (Figure 5(3)).

Research Question 2: Do students use relational structures of the source analog (foam) to reason about target concepts in plate tectonics?

Carry's Understanding of the Role of Density in Plate Tectonics

Prior to the Paper Plates exercise, Ms. Kelly explains to the students that the objective of their next assignment is to use their knowledge of the foam interaction in order to think about what is happening at the plate boundaries. As an example, Ms. Kelly asks what should happen

when continental crust converges with oceanic crust. She first calls on Carry to predict what happens when the two kinds of foam (A and B) converge.

Ms.

Kelly: What should happen...

[Ms. Kelly picks up both pieces of foam and holds them next to each other. Foam A is stage right and foam B is stage left] What should happen when they are at a convergent plate boundary? So go back to the foam. So even...so you can't just say, "oh look Michelle you push this...I'll push this...let's see what happens"...right? OK? You actually have to make something happen because what you know about this...about the foam. So Carry, what should happen?



Figure 6. Ms. Kelly holding two pieces of foam: foam A (on the right) and foam B (on the left).

Carry: Well, it should probably go up...like it should probably pu...if you push i/
[holds right hand over left hand]

Ms.

Kelly: /Come over here and show me.

[Carry walks up to the front of the class] We don't have to do the pushing but tell me what you...what you remember



Figure 7. Carry's gesturing with her right fingers over her left fingers.

Carry: Like...um...well, like, you just push...if you push them together, it will go up

Ms.

Kelly: which one...which one...which one will go down, and which one will go up? What do you remember from this from the work about foam A and B?

Carry: I (inaudible)

Ms.

Kelly: You don't really remember?



Figure 8. Carry grasps the end of the foam

Ms.

Kelly: So you know what I was thinking/

Carry: /well like I think it was this one [hits hand on foam A]



Figure 9. Carry patting hand on foam A.

Summary of Carry's Understanding of the Role of Density in Plate Tectonics

In this vignette, Carry's expressed models consisted of verbal and gestural modes of representations. The verbal representation, "it should probably go up," denotes the behavior of the foam, and "if you push them together, it will go up," shows some level of understanding about a mechanism that produces the behavior; however, these expressions lack in representing the structure of the analog model. It is unclear as to which side goes up. The gestural model in Figure 7 shows the right hand moving over the left hand, which could be inferred to map to the

foam in Ms. Kelly's hands from the perspective of Carry's location with foam A (on the right) and foam B (on the left) (Figure 6).

It appears from the verbal expression "well like I think it was this one" that Carry recalls which foam is the one that should go up. The additional gestural signification with her hand patting foam A (Figure 9) also emphasizes this as well. Though Carry does begin to remember, Ms. Kelly moves forward with the discussion by suggesting the students are given their matrix worksheets back for reference.

Mary's Understanding of the Role of Density in Plate Tectonics

Another student (Mary) volunteers to explain what happens when the two pieces of foam are pushed together and why. Ms. Kelly calls Mary to the front of the class to explain. At first, Mary has trouble with a particular word, but after a little help from a peer, she moves steadily forward with her explanation:

Mary: I forgot the word but like how how like that word (inaudible) foam B [points to foam B] I forgot that word.



Figure 10. Marry pointing to foam B.

Student: Density?

Ms. Kelly: Dense?

Mary: Yeah, dense, like since it was more dense, foam A would go up [moves foam A above foam B] because it's like if it was a boat... if these were two boats, and and like thi... this boat [hits hand on foam B] had like more stuff on it, then this one would go a little higher [raises foam A above foam B], and this one [puts hand on foam B] would go a little lower because this stuff on the boat was pushing it lower. So it's kind of like it would just go up. [pushes foam A up and over the top of foam B]



Figure 11. Mary lifting foam A above foam B.

Ms. Kelly: So are you saying that because this foam [points to foam B] is more dense than this foam [points to foam A] that it would go down [bends foam B down]...

Mary: Yeah.

Ms. Kelly: and this would go up?

Mary: Yeah.



Figure 12. Ms. Kelly pushing down foam B and pulling up foam A.

Summary of Mary's Understanding of the Role of Density in Plate Tectonics

Mary used the foam analog model and the boat analogy to help describe her understanding of the interactions between oceanic crust and continental crust at a convergent plate boundary. In her expressed model, the verbal representation was used to narrate the behavior of the plates, while the foam analog model was used to demonstrate, in a *deterministic* way—its behavior was predictable, —the *location* of the plates throughout the sequence. The parallels between the verbal and concrete representations seemed to be challenging for Mary to

express on a *semantic* level; however, her use of gestures provided the necessary *emphasis* needed for the expressed model to effectively communicate her mental model to Ms. Kelly. Evidence for this is suggested by Ms. Kelly's more concise expressed model to verify, and as well as revoice to Mary and the other students, what Mary expressed. One thing to note when judging the effectiveness of Mary's model, however, is that it had a highly *pragmatic* semiotic level. In other words, Ms. Kelly was well familiar with the situation in addition to the communication conventions of most third-graders.

Switching Representations Through Abstract Structure

A group of three students must use Earthquake data on three different fault boundary types to find out which type of plate boundary would likely produce the largest magnitude Earthquake. Stacy and John begin to argue between which of the two fault boundary types, divergent (John's choice) or transform (Stacy's choice), can likely produce a larger magnitude. Stacy notices that there is oceanic crust on one side of the fault and continental crust on the other side.

Stacy: Its continental [hits left hand on table with thumb pointing to the continental side of the map] vs. oceanic [with a chopping motion, hits right hand on the oceanic side of the map figure]

John: So that would (inaudible)

Stacy: One.... foam A and one foam B.
One foam A and one foam B

John: What?

Stacy: One foam A and one foam B. One foam A and one foam B
[gets up from her chair to get two of the foam pieces (A and B foams)]



Figure 13. Stacy (on left) pointing to the oceanic side of map figure.

Stacy, John, and Mary arrange the foam so the two pieces are side-by-side similar to the foam boundary exercise. They begin to run the model just like they were instructed during the foam activity they did in the previous class.



Figure 14. John, Stacy, and Mary running the analog model with foam A and foam B.

Stacy: well it doesn't perfectly glide like a regular (inaudible)...the boundaries like wavy [gestures s-pattern on piece of map]



Figure 15. Stacy making an s-pattern with her finger to emphasize the non-linear boundary on the map figure.

Stacy: see, it's kind of like this
[manipulates foam to produce a
wave-like pattern]. See... it's like
wavy, like that. See how its
wavy...see how it's wavy?

John: (inaudible)

Stacy: The boundary is... [talk is
interrupted by a bouncing piece of
foam]...The boundary is wavy.
That means it can create more
(inaudible).



Figure 16. Stacy tries to contort the model in order to show her hypothesis.

The students make their way back to the rest of the maps at their table. After a brief discussion with the teacher, the students still have not reached an agreement about the plate boundaries. One thing to note, however, the students still have not yet studied the convergent boundary map which was assigned to them. Stacy and John still debate between the divergent and transform boundaries.

Stacy: I still think its transform because
it's because it's like this

John: oh my god you stole it

Stacy: its mine! Because it it does this
[puts knuckles together],
look...Look it does this [moves
knuckles in a similar way the
foam was moved], which creates
more friction than that. And when
it does that [taps on the divergent
boundary map piece].



Figure 17. Stacy demonstrates her hypothesis using her knuckles as the plate boundary.

John: Yeah, but are we talking about friction? No, we're talking about what makes (inaudible) Earthquakes!/
Stacy: /It's an example! /

John: /and that's divergent.

Stacy: Cause when it does this it creates more friction to create... Stop hitting me!

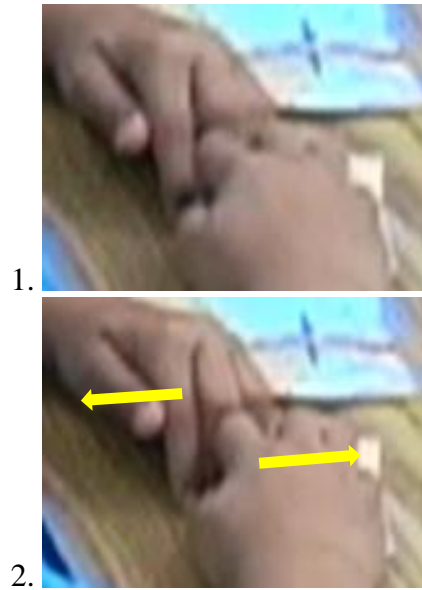


Figure 18. Close-up of Stacy's hands: sequence showing (1) initial position of seated knuckles and (2) final position of knuckles after being forced out of their seating. Arrows show direction of travel.

Stacy: It does this to create more friction, which creates a bigger Earthquake than that [slams hand on divergent boundary map].

John: I think it's divergent because divergent spreads apart.

Stacy: How does that create an Earthquake?

John: Alright, fine.

Mary: (inaudible)

John: (inaudible)

Stacy No, it makes friction to create stronger Earthquakes [models the strike slip fault with her hand again] than that [taps the divergent boundary figure]. It it [puts both hands on divergent boundary map figure and points to the arrows] barely creates friction to create an Earthquake, so how how about that?



Figure 19. Image of Stacy slamming her hand onto the divergent plate boundary map.

Summary of Switching Representations Through Abstract Structure

In this vignette, Stacy begins with examining a map showing a transform fault boundary and tries to convince John that this boundary type will produce stronger magnitude Earthquakes than the divergent boundary. In her struggles to convince John, she suggests they model the boundary with the foam representing the two kinds of crust as interpreted from the map. Stacy began to focus on the bend in the boundary as the possible cause for the stronger Earthquakes. She realizes quickly that the physical structure of the model must be manipulated in order for it to create the stronger Earthquakes.

Although the model did not produce the desired results, which could have easily been solved by applying different points of force to bend the foam, or by cutting an s-pattern into the side of each piece of foam, Stacy was able to switch to her knuckles as a gestural model in order to show how the bend in the boundary could cause more friction, and thus, stronger Earthquakes.

Identifying the differences between the target analog (the bending transform boundary) and the source analog (the foam analog model), and creating a new model with her hands is evidence that Stacy has some understanding of an abstract relational structure between the target, the ideal foam analog model, and her gestural model.

Research Question 3: How do students' ideas about plate tectonics change throughout the unit?

Twenty-three (13 boys and 10 girls) took both the pre- and post-test. Scores on the test overall and for each sub-scale assessed are shown in Table 3. Table 3 also shows the results of paired samples t-tests computed for the tests overall and for each sub-scale. Overall, students' performance improved significantly, although the mean difference represents only about a 10% gain.

Table 3.

Paired sample t-tests for pre-test vs. post-test scores (Categories: PT-Plate Tectonics, EI-Earth's Interior, EQ-Earthquakes, and OP-Other Processes)

Topic	n	Max	Pre-test	Post-test	Difference	p-value	t-statistic
Overall	23	16	3.22 (1.24)	4.74(1.68)	1.522	0.002*	3.155
PT	23	7	1.83 (.89)	2.91 (.90)	1.087	0.00003*	5.009
EI	23	3	0.43 (.66)	0.52 (.67)	0.087	0.352	0.385
EQ	23	3	0.22 (.42)	0.26 (.45)	0.043	0.357	0.371
OP	23	3	0.65 (.57)	0.87 (.69)	0.217	0.154	1.045

* $p < .05$

DISCUSSION

This study set out to develop and explore a teaching model aimed to improve learners' familiarity of the key analogical features in a source analog prior to introducing (or using) an analogy for understanding a target domain. The focus of this thesis is on how students built an understanding of concepts in plate tectonics through the use of a physical analog model and on findings that may be used to further develop and study this analogical teaching approach. Thus, the primary goal here is to discover evidence for the viability of the Pre-Analogy Step (PAS) and to highlight some of the challenges future research designs for studying PAS should take into account.

In order to find evidence to support this goal, I used interactional analysis of students in video recorded whole-class discussion and small-group activities to, first, determine if students demonstrated an understanding of the source analog's relational structures during the PAS phases of instruction. Second, the analysis sought to determine how students used a physical analog model to reason about target concepts in plate tectonics. Lastly, a statistical analysis of a pre- and

post-test was used to understand how students' ideas about plate tectonics changed throughout the unit.

Analogical Teaching Strategies and the Pre-Analogy Step

The effectiveness of teaching with analogies relies heavily on the approach taken by the teacher (Treagust, Duit, Joslin, & Lindauer, 1992), and therefore, researchers have developed various strategies for teaching with analogies in the classroom (i.e. Brown & Clement, 1989; Bulgren, Deshler, Schumaker, & Lenz, 2000; Dupin & Johsua, 1989; Else, Clement, & Rea-Ramirez, 2008; Glynn, 2007; Harrison & Treagust, 1993; Treagust, Harrison, & Venville, 1998; Zeitoun, 1984). These strategies typically involve a set of procedures teachers can perform during instruction to present the source and target in such a way that will make reasoning with the analogy easier for the students. Some of these strategies include lesson planning steps, such as measuring students understanding of analogies and their familiarity of the topic/concept to be learned (Treagust, Harrison, & Venville, 1998; Zeitoun, 1984). Most strategies focus only on steps used once the analogy has been introduced, and recommend having the teacher assist with the analogical mapping in order to make up for any lack of students' source analog familiarity, which is a vital part of reasoning with analogies (Gentner & Gentner, 1983; Harrison & Treagust, 1993). During the pre-lesson phase of the Focus—Action—Reflection (FAR) method (Harrison & Coll, 2007; Treagust, Harrison, & Venville, 1998), the teacher is supposed to find a familiar experience of the students, which is to be used as the source analog; however, the measure of familiarity is far more challenging to obtain than people tend to realize (Kamas & Reder, 1995). The theoretical framework behind PAS assumes familiarity of common experiences is low and varies among students. This thesis suggests that the PAS has a unique quality, in that (1) it can enhance students' source analog familiarity, and (2) it can be used along with any one of the other strategies for teaching with analogies.

Student Understanding of the Source Analog During PAS

For a person to obtain familiarity of the details of an object or experience, whether common or not, the person usually must possess a need to understand such details (Nickerson & Adams, 1979). Assigning an observational task to the students for homework is one method for producing this need. Additionally, the task can also provide students with an exercise in making observations. This was the method used for PAS phase-1 in this study. The students were asked to make some observations about the various kinds of foam in their home and to take notes on these observations because they would be useful during their next classroom discussion.

Then, in phase-2, the need for understanding the details of the analogous material was expanded by motivating the students through a discussion of what they observed. In addition to hearing about the characteristics of the foam from their classmates, students had to access their memory of their own observations. The process of accessing one's own memory is key for developing and increasing accessibility of long-term memory (Kamas & Reder, 1995). For the teacher, the primary objective here was to guide the students' ideas about the characteristics of foam for which a consensus model is co-constructed with the teacher (Clement, 2008).

Due to unknown circumstances the video data for day-1 of the educational unit was unavailable for analysis. This made it challenging to ascertain students' understanding of the foam during PAS phases 1, 2, and part of 3, as well as to find ways in which specific PAS experiences from these phases may have influenced how students reasoned analogically about concepts in plate tectonics.

One way that PAS can strengthen familiarity is through the teacher and students' co-construction of a consensus model of the foam source analog. This can help students develop a shared understanding of source attributes and terminology. For example, PAS phase-4 involved a whole-class discussion to collectively review students' previous observations from phase-3, and

introduced new terminology based on their expressed models. As seen in the vignette above (intro to density-day2), this method invited students to express their ideas under a particular set of phenomena. This made it possible for the teacher to pull together students' expressed models in order to build one comprehensive idea that was used by the teacher to introduce new concepts (i.e. plate boundaries, density, and elasticity). Students were not simply tossing their ideas out onto an idea pile. Their ideas were being strategically situated into a new conceptual framework. The students did not appear to have been contributing well-formed conceptual models, or to have individually connected one idea with another without the guidance of the teacher. Certainly, we could not determine with certainty from simply observing their behavior in the video. Nor could we determine with certainty students' initial complete mental models when the teacher introduced the new concepts. Students did, however, recall characteristics of the foam analog and related concepts. Eliciting students' own ideas and guiding them in this way may have helped them to understand and use the analog model. Students' frequent recollection of the foam analog may have played one of the most important roles in refining and strengthening recall of their mental models. During the PAS phases of this instructional unit, students were able to express many of their own ideas about the foam, which Ms. Kelly was able to guide toward a shared understanding in order to introduce new terminology and concepts, which would then prove useful in the later part of the instructional unit.

Students' Use of a Physical Analog Model

Throughout the instructional unit, students were encouraged to use the foam analog model to help them reason about many of the questions they were asked to answer. In addition to the many instances in which Ms. Kelly reminded students to "think back to the foam," students were free to pick-up the foam at any time during the small group activities. The shift in focus from learning about the foam analog to learning about plate tectonics gradually emerged in PAS

phase-4 as the concepts became more abundant within the students talk. The goal was to give students a sense that these new concepts were already very much a part of their understanding, although applied to a new context.

Students' demonstration using both verbal and gestural modes in their expressed models of how the foam analog behaved indicated that students understood the relational structure at a level of simple relations (Gentner, 1983; Kastens & Rivet, 2010). This is apparent in John's description of the spreading center concept in terms of the foam blocks moving away from each other (from p. 28), as well as in John, Stacy, and Mary's transparent switching between the foam and map as they work out how plate boundaries might stick and release to cause Earthquakes (pp. 35-38).

The ability to evaluate and refine higher order relational correspondences (Gentner & Smith, 2012) and reason with abstractions developed during the analogical reasoning process (Holyoak, 2012) are both evidence of learning. These kinds of actions could provide strong evidence to suggest PAS helped students build a mental model from which they were able to focus better on the relational structure needed to make inferences about a target analog. One example of this may be found in the episode in which Stacy took the initiative to use the foam model to try and solve a particular problem during small group activities. Stacy showed signs of abstracting relational structure from the map and foam models to produce a gestural model, which she then used to argue which boundary type produces stronger Earthquakes. Other students would utilize the model to reason about many of the activities; however, Stacy's case provided the only clear opportunity to observe these actions. It also shows us that there is more to discover about the potential effects of PAS may have on enhancing source analog familiarity.

Accessing the Source Analog

Recall of the source analog seemed to vary throughout the educational unit. Terminology seemed to be challenging, but students were able to use the concepts after some help recalling the word. Still, this was not surprising given the age of these students and difficulty of the words themselves. The cues from Ms. Kelly may have helped to reduce recall deficiencies. Though it is unclear as to why Carry would have trouble recalling that foam A moved over foam B. During the episode in which students needed to show the role of crustal density in the behavior of the Earth's plates at a convergent boundary, Carry's expressed model did not involve modeling with the foam nor was it as complex in contrast to Mary's expressed model. Carry seemed to have picked up on these aspects of the source analog in previous activities. For example, in phase-3 of PAS, Carry performed the AB convergent simulation in which foam A moved over foam B and described this to Ms. Kelly in a verbal and gestural representation. Then, during the introduction of density on day 3, Carry showed clear understanding of the effects density may have on the plates. In this vignette, however, Carry was under pressure to answer Ms. Kelly's question, which can play a role in properly mapping an analogy (Gentner & Smith, 2012). The situation may have required more cues or, at least, a little more time since Carry was able to recall her answer just before Mary was called on to give her answer.

Mary had not been under the same pressure as Carry, and she had more time to formulate her answer. Once she was able to recall the word, density, her conceptual understanding of the role of crustal density in the behavior of the Earth's plates at a convergent boundary was apparent. In addition, she was able to recall and apply the boat analogy learned during PAS phase-4. Utilizing multiple representations by cueing Carry to think back to the boat analogy would have been a good approach to help Carry with her answer (Chiu & Lin, 2005; Gutwill, Frederiksen, & White, 1999; Kwon & Noh, 2001; Sell, Herbert, Stuessy, & Schielack, 2006).

Future PAS research would benefit from controlling for time and pressure; however, there are many factors at play within the classroom learning environment. Thus, sifting through these to weigh out any effects a teaching approach like this has on student learning takes a tremendous effort in research design to a highly rigorous analysis. Identifying these needs is one of the goals of this study.

How Students' Ideas About Plate Tectonics Changed Throughout the Unit

Students' improved performance on the post-test was due to improvement in their responses to questions about plate tectonics. Topics in the other three categories (Earthquakes, Earth's interior, and other processes), did not show a significant increase. We can infer two causes for these low scores. First, the specific concepts in many of these questions were simply not covered in class. For example, many of the students' answers from pre- to post-test did not change for test items 8 and 12, which were not covered. Whereas, covered concepts, such as items 10 and 15, had the largest gains. Differences such as these help to verify that gains were likely not attributed to students guessing. If they were, many of the test items for the covered topics would likely show similar scores in which many of the students' answers did not change from pre- to post-test.

Low scores on items 3, 6, 7, and 11 may have been due to the way the test questions were set up. Though many students chose the correct option, the majority also chose one of the incorrect options. For example, on test item 3, only two students chose the correct answer (D) alone; however, 18 other students also chose D along with a combination of incorrect responses as well (see APPENDIX B). A post interview with these students may have provided a better picture of students' ideas regarding these test items.

Though it was possible to connect test items to specific learning activities after PAS, such as item 10 and the whole group activity on the location of Earth's tectonic plates, connecting

these directly to students' PAS experience proved to be much more challenging. The physical analog model focused students' attention on the characteristics of plates and plate boundary types, whereas the pre-/post-test focused more on other aspects of plate tectonics and related topics. Future research on PAS should directly test for concept knowledge that includes concepts with relational structure corresponding to aspects of the source analog.

Limitations

In addition to the limited availability of video as noted above, another limitation was the amount of usable video. There was only one camera, which needed to be controlled at all times because there were restrictions on how some of the students could be recorded. This made it challenging to record more than one group of students at a time.

Sound quality was poor due to either too much noise in the room, a misdirected microphone, or disturbance of the microphone by the students or videographer. Having a second sound recording device would have made it easier to identify talk which was inaudible in the video recording.

The pre-/post-test presented a third limitation to this study. The instructional unit included a unique teaching method to teach students about very specific concepts within a broad topic. The pre-/post-test should have included more questions which were directly related to the specific target concepts covered in the unit in order to obtain a better view of student learning.

Closing Remarks

The research on analogical reasoning, teaching with analogies, and memory for common objects suggests that increasing students' source analog familiarity will increase the efficacy of teaching with analogies. The use of analogies in education is recognized to have the ability to help (Richland, Morrison, & Holyoak, 2006) or hurt student learning (Duit, 1991; Treagust, Duit,

Joslin, & Lindauer, 1992). It is important to strive to develop and improve methods for teaching with analogies (Treagust, 1993). Familiarity of the source analog is a vital part of reasoning with analogies (Gentner & Gentner, 1983; Harrison & Treagust, 1993); however, familiarity is far more challenging to obtain (Kamas & Reder, 1995).

The Pre-Analogy Step (PAS) is a teaching method aimed to improve learners' familiarity of the key analogical features in a source analog prior to introducing (or using) an analogy for understanding a target domain. This method is designed to improve the efficacy of an analogical teaching approach by (1) facilitating stronger familiarity of the source analog and (2) facilitating proper mapping between the source and target analogs as well. It is clear that there is more work ahead to provide strong evidence for the viability of the Pre-Analogy Step; however, this study highlights some of the challenges future research designs should take into account for obtaining this goal.

APPENDIX A. Pre-/Post Test

Name : _____ Date: _____

Directions:

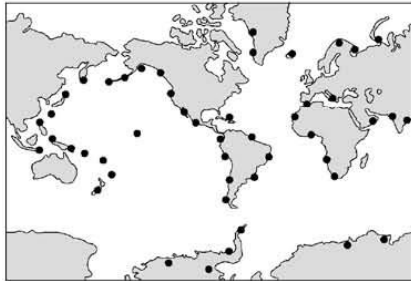
Read each question carefully and CIRCLE your answer.

1. Which is the best definition of a tectonic plate? (**rigid means stiff**)
 - A. All solid, rigid rock beneath the continents and above deeper, moving rock
 - B. All solid, rigid rock beneath the continents and oceans and above deeper, moving rock
 - C. All solid, rigid rock that lies beneath the layer of loose dirt at the Earth's surface and above deeper, moving rock
 - D. All solid, rigid rock and loose dirt beneath the Earth's surface and above deeper, moving rock**
 - E. The rigid material of the outer core

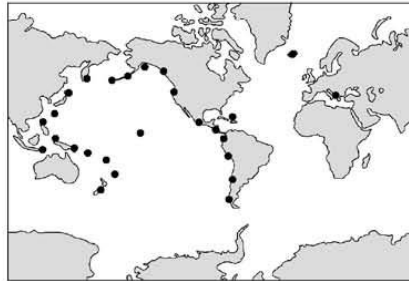
2. Some people believe that they have evidence that can prove whether the very center of the Earth is a solid, liquid, or gas. Which of the following is an accurate statement about the innermost part of the Earth?
 - A. The very center of the Earth is mostly made up of gases
 - B. The very center of the Earth is mostly made up of liquids
 - C. The very center of the Earth is mostly made up of solids**
 - D. We do not know the state of the very center of the Earth

3. Which of the following are associated with events that cause large earthquakes? **You may circle more than one.**
 - A. Buildings falling
 - B. Weather changing
 - C. Bombs dropping
 - D. Continents moving**
 - E. Earth's core changing

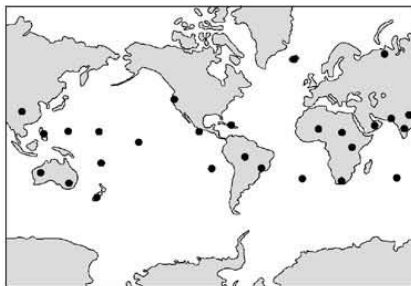
4. The following maps show the position of the Earth's continents and oceans. The gray areas represent the land and the white areas represent water. The black dot's on each map mark the locations where volcanic eruptions occur on land. Which map do you think most closely represents the places where these volcanoes are typically observed? Make sure to read the captions below each picture. Circle your choice.



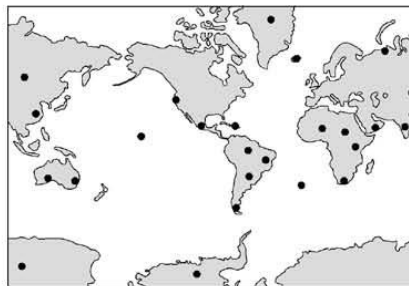
A. Mostly along the edges of the Pacific and Atlantic Oceans



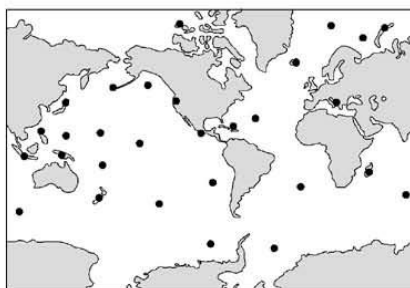
B. Mostly along the edges of the Pacific Ocean



C. Mostly in warm climates

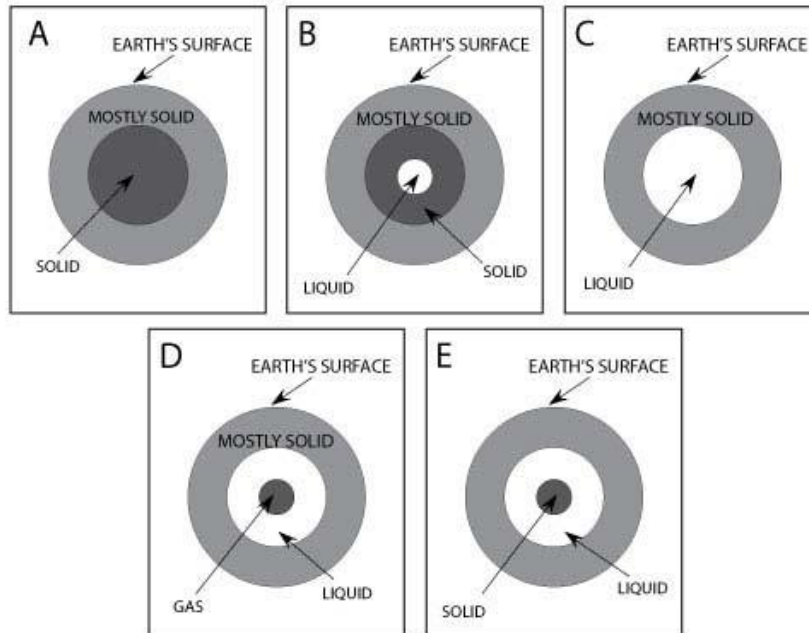


D. Mostly on continents



E. Mostly on islands

5. Which of the following figures do you believe looks most like what you might see if you could cut the Earth in half?



(Answer = E)

6. Which of the following strategies do you think scientists can use to gather evidence about whether the very center of the Earth is mostly a solid, a liquid, or a gas?

You may circle more than one.

- A. Drilling through the center of the Earth
- B. **Studying motion caused by earthquakes**
- C. Analyzing pictures taken by satellites
- D. Scientists cannot study the center of the Earth

7. Which of the following best describes mountains? You may circle more than one.

- A. Old mountains are taller than young mountains because old mountains have been growing longer.
- B. Old mountains have gentler slopes than young mountains because old mountains have been wearing down longer.**
- C. Old mountains have more vegetation than young mountains because old mountains have had plants growing on them longer.
- D. Old mountains have rougher surfaces than young mountains because old mountains have been around longer.
- E. All mountains are roughly the same age regardless of shape, size, vegetation or roughness.

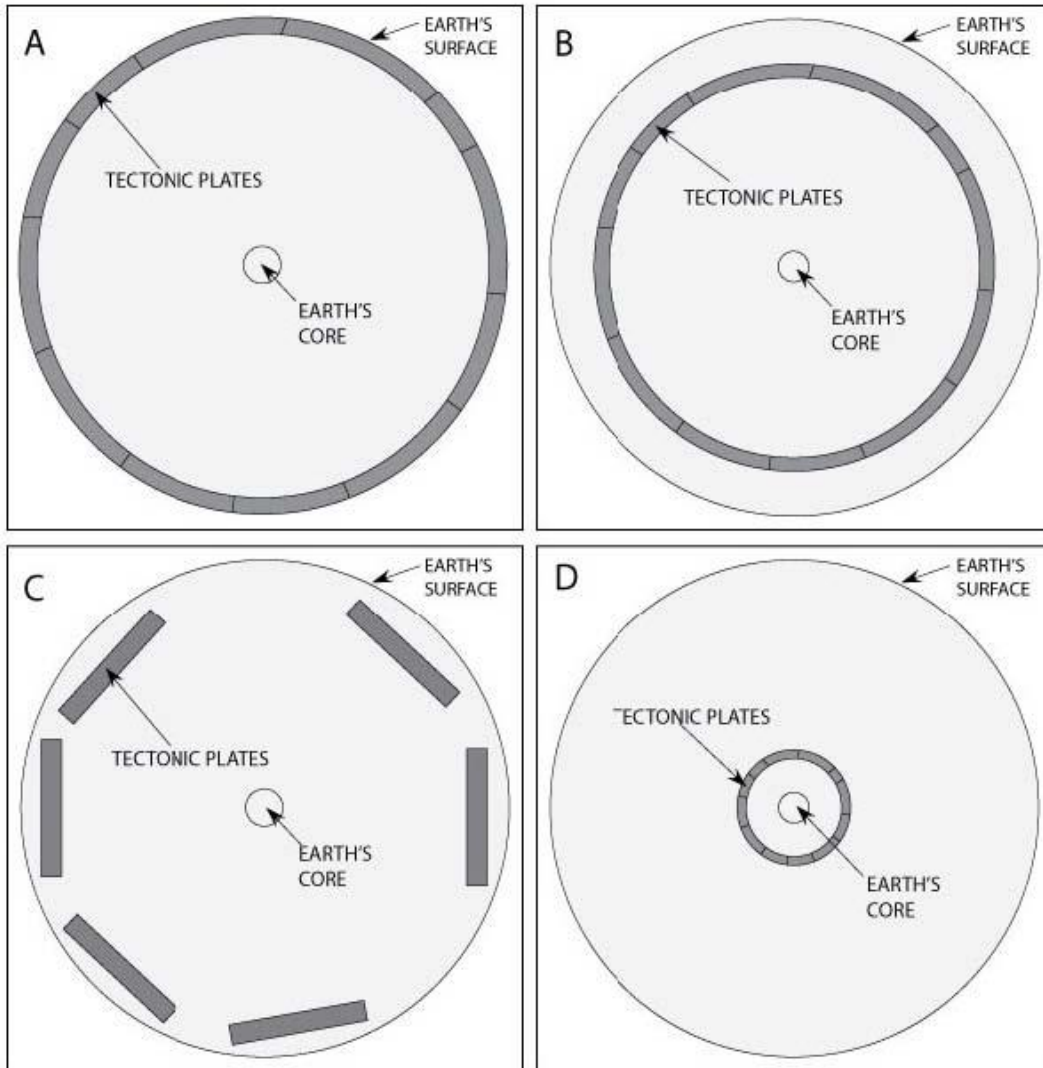
8. What is the relationship between rock formation and Earth's surface?

- A. Most rocks form underground and reach the Earth's surface as molten rock moves.
- B. Most rocks form underground and reach the Earth's surface as other rocks are destroyed.**
- C. Most rocks form underground and never reach the Earth's surface.
- D. Most rocks form at the Earth's surface and stay there for a long time.

9. What causes most of the waves in the ocean?

- A. Tides
- B. Earthquakes
- C. Wind**
- D. Tsunamis

10. Scientists often talk about the Earth's tectonic plates and their role in mountain formation, volcanism, and earthquake occurrence. Which of the following figures most closely represents the location of the Earth's tectonic plates?



(Answer = A)

11. Which of the following describes what scientists mean when they use the word “earthquake”. **You may circle more than one.**

- A. When an earthquake occurs, visible cracks appear on the Earth's surface
- B. When an earthquake occurs, people can feel the Earth shake
- C. When an earthquake occurs, man-made structures are damaged
- D. When an earthquake occurs, energy is released from inside the Earth**
- E. When an earthquake occurs, the gravitational pull of the Earth increases

12. Which of the following statements best explains the relationship between volcanoes, large earthquakes, and tectonic plates?

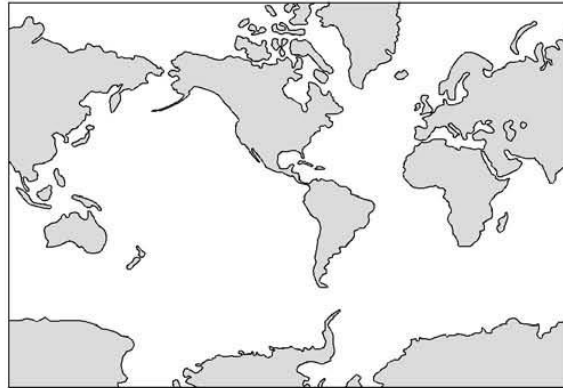
- A. Volcanoes typically occur on islands, earthquakes typically occur on continents, and both occur near tectonic plates
- B. Volcanoes and large earthquakes both typically occur along the edges of tectonic plates**
- C. Volcanoes typically occur in the center of tectonic plates and large earthquakes typically occur along the edges of tectonic plates
- D. Volcanoes and large earthquakes both typically occur in warm climates
- E. Volcanoes, large earthquakes, and tectonic plates are not related, and each can occur in different places

13. What is the best explanation for the movement of tectonic plates?

- A. Lava moves the tectonic plates
- B. Currents in the ocean move the tectonic plates
- C. Earthquakes move the tectonic plates
- D. Gravity moves the tectonic plates**
- E. Magnetism moves the tectonic plates

14. The map below shows the position of the Earth's continents and oceans today. The gray areas represent land, and the white represents water. Which of the following best explains why the ocean basins look the way they do?

(a basin is an area where water is held)



- A. Meteor impacts caused the ocean basins to form this way
- B. Continents moving caused the ocean basins to form this way**
- C. The Earth cooling caused the ocean basins to form this way
- D. The Earth warming caused the ocean basins to form this way

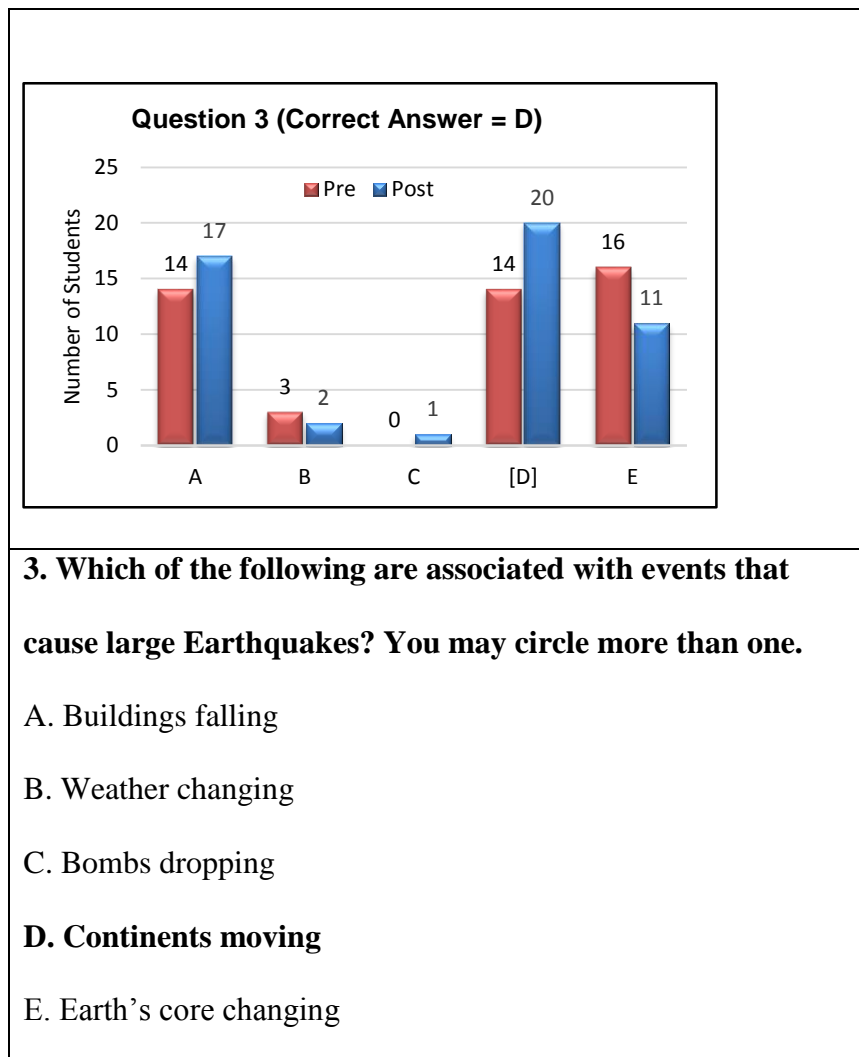
15. How far do you think continents move in a single year?

- A. A few inches**
- B. A few hundred feet
- C. A few miles
- D. We have no way of knowing
- E. Continents do not move

16. Some people believe there was once a single continent on Earth. Which of the following statements best describes what happened to this continent?

- A. Meteors hit the Earth, causing the continent to break into smaller pieces
- B. The Earth lost heat over time, causing the continent to break into smaller pieces
- C. Material beneath the continent moved, causing the continent to break into smaller pieces**
- D. The Earth gained heat over time, causing the continent to break into smaller pieces
- E. The continents have always been in roughly the same place as they are today

APPENDIX B. Chart showing all answers chosen for test item 3 in both pre- and post-test.



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