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Discovering Plate Boundaries in Data-integrated Environments: Preservice Teachers' Conceptualization and Implementation of Scientific Practices

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Drawn from the norms and rules of their fields, scientists use variety of practices, such as asking questions and arguing based on evidence, to engage in research that will contribute to our understanding of Earth and beyond. In this study, we explore how preservice teachers' learn to teach scientific practices while teaching plate tectonic theory. In particular, our aim is to observe which scientific practices preservice teachers use while teaching an earth science unit, how do they integrate these practices into their lessons, and what challenges do they face during their first time teaching of an earth science content area integrated with scientific practices. The study is designed as a qualitative, exploratory case study of seven preservice teachers while they were learning to teach plate tectonic theory to a group of middle school students. The data were driven from the video records and artifacts of the preservice teachers' learning and teaching processes as well as written reflections on the teaching. Intertextual discourse analysis was used to understand what scientific practices preservice teachers choose to integrate into their teaching experience. Our results showed that preservice teachers chose to focus on four aspects of scientific practices: (1) employing historical understanding of how the theory emerged, (2) encouraging the use of evidence to build up a theory, (3) observation and interpretation of data maps, and (4) collaborative practices in making up the theory. For each of these practices, we also looked at the common challenges faced by preservice teachers by using constant comparative analysis. We observed the practices that preservice teachers decided to use and the challenges they faced, which were determined by what might have come as in their personal history as learners. Therefore, in order to strengthen preservice teachers' background, college courses should be arranged to teach important scientific ideas through scientific practices. In addition, such practices should also reflect the authentic practices of earth scientists such as use of historical record and differentiating observation versus interpretation.

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Introduction

Within communities of science, individuals follow certain practices to engage in to construction of knowledge in their discipline such as using multiple lines of evidence to build strong scientific explanations. These scientific practices can help understanding reasons behind and discussions on core scientific ideas such as energy and weather and climate (Reiser, Berland, & Kenyon, 2012). The US National Research Council (NRC)'s report *Taking science to school: Learning and teaching science in grades K-8* emphasized the importance of teaching science as practice and using instruction methods that will support students to achieve a more sophisticated understanding of these scientific practices (2007b). This emphasis has been expanded in two recent documents that guide the US education system: the *Framework for K-12 standards* (NRC, 2012) and the *Next generation science standards* (NGSS Lead States, 2013). Following the suggested emphases of these reports will result in the replacement of 'teaching science as inquiry' with 'teaching science as practice'. One reason for this change in emphasis is the differing goals between inquiry and what researchers and educators aim for in science education. For example, scientists use inquiry to contribute to the body of existing scientific knowledge, whereas in science classrooms we want our students to understand the process of inquiry and simultaneously learn well-established ideas in science. Another reason is the ambiguous meaning of the concept of inquiry that makes it challenging for teachers to implement it in K-12 classrooms for that is, classrooms span from kindergarten to 12th grade that includes students from ages 5–18 years (Osborne, 2014). We can instead use more specific 'practices' to help teachers understand the general term 'scientific inquiry'. The *NRC framework* (2012) defines scientific practices and makes a solid distinction between skills and practices 'to emphasize that engaging in scientific investigation requires not only skill but also knowledge that is specific to each practice' (p. 30).

A key element to achieve the goal of teaching science as practice is to engage students in the scientific discourse, which is the specialized language shared by scientists in their discipline. This discourse includes unique meaning of words and symbols and interpretations of inscriptions. Teachers have an important role in guiding this discourse in K-12 classrooms (NRC, 2007a, 2012). This essential role of teachers in guiding appropriate discourse requires reforming teacher education programs to focus on their understanding of the scientific practices, for example, as suggested in NGSS (Bybee, 2014). The NRC document's focus on scientific practices is promising and can lead to better understanding of how scientific knowledge is constructed or theories developed in various science disciplines. In this study, we explore how preservice teachers' learn to teach scientific practices while teaching plate tectonic theory. In particular, our aim is to observe which scientific practices preservice teachers use while teaching an earth science unit, how do they integrate these practices into their lessons, and what challenges they face during their first time teaching in an earth science content area integrated with scientific practices.

Theoretical Background

This study is grounded in cultural–historical ways of knowing, learning, and teaching. According to cultural–historical theory, subjects engage into an activity that is shaped by the norms and rules of the community to achieve certain learning outcomes. The subjects reach these learning outcomes through tools or mediating artifacts and through division of labor among the participants of the community (Engeström, Miettinen, & Punamäki, 1999). The division of labor, in this theory, means that roles are distributed to the members of the community to achieve a shared outcome. The historical background and previous experiences of every subject play an important role in the construction of knowledge and how each subject experiences the activity (Fleer & Pramling, 2014). We use this theory to explain (a) scientists' way of knowing (b) practices that became a norm in scientists' disciplinary culture, and (c) how preservice teachers learn to teach plate tectonic theory.

First, we consider the community of scientists engaging in the construction of knowledge for plate boundary processes. These scientists use data maps as a visual tool/mediating artifact. A combination of data maps from the fields of volcanology, seismology, geography, and geochronology is used to explain the categories and formation of plate boundaries. The data maps also show us the variety in the historical background of scientists involved in the development of the theory. Moreover, earth scientists have developed a vocabulary to describe the types of boundaries (e.g. convergent/divergent/transform).

Second, we discuss how scientific practices are shaped within the discipline, or community, by the cultural norms and backgrounds of the scientists involved. Although the aforementioned documents in the USA describe scientific practices for science as a whole, it is important to understand how these practices have specific implementations in different disciplines. The types of research conducted by different disciplines result in different philosophical perspectives, although many practitioners may not recognize these perspectives. Philosophical perspectives of each discipline can show differences in the scientific practices and thus might have varying pedagogical implementations (Erduran, 2014). In an example where Erduran (2014, p. 101) asks students the difference between the periodic law and the law of gravitation, she receives responses that express similarities (e.g. 'A Law is a generalization') as well as responses that highlight the differences. ('The periodic law cannot be expressed in an algebraic form while the law of gravitation can be.') In our study, our goal is to extend this approach to earth science, and to plate tectonic theory in particular.

Third, we use cultural–historical theory to analyze preservice teachers' learning process with regard to teaching plate boundaries (Sezen-Barrie, Tran, McDonald, & Kelly, 2014). In the learning environment we provided tools for preservice teachers to understand how scientists, in collaboration with other scientists and institutions, developed mediating artifacts (data maps) for use in the development of plate tectonic theory. We also looked at how these preservice teachers use other tools or mediating artifacts such as resources provided to them to learn and discuss plate boundary processes. We designed a learning environment to encourage division of labor among their peers (e.g. preservice teachers are divided into groups to study the map of different specialty groups and share with the rest of the class). Preservice teachers also learn to teach by reflecting on their interaction with students in the middle school community, thus providing another division of labor. We interpreted the findings of the study by considering the historical background of preservice teachers (i.e. the science courses they took and teaching experience they have).

The three aspects of using cultural historical theory—construction of scientific knowledge, defining scientific practices, and preservice teachers' learning—will be apparent on the description of educational content, the data we choose to collect, and conclusions we draw based on our findings. Before we move to explaining the implications of scientific practices in the USA for earth science education and how teachers learn to teach earth science as integrated with scientific practices, we will give a brief review of the status of earth science in K-12 education.

The Status of Earth Science in K-12 Education

Until the end of the nineteenth century, earth science was typically taught as part of the mandatory high school science curriculum in the USA but by 1910 had become largely an elective course (Dodick & Orion, 2003). Since then earth science content has not been a large part of K-12 school curriculum in most states, college preparation (LaDue & Clark, 2012), or college admission (Schaffer, 2012). Teaching of earth science content has been minimal, in part, because many did not consider earth science content as 'rigorous' as the other three domains of science: life sciences, physical sciences, and chemistry (Hoffman & Barstow, 2007). For example, when K-12 and college earth science educators were asked about 'the three biggest hurdles facing the geoscience education', common types of responses about perception of earth science included: 'Earth Science is for students not good at science', 'a lack of access to Earth science learning in K-12', 'the perception of Earth Science as "rocks for jocks"—Earth Science has an image problem', 'weak representation in state standards', and 'not recognized as a serious science against biology, chemistry, and physics' (LaDue & Clark, 2012, p. 376).

Earth science is an interdisciplinary and integrated science that helps us understand the interdependence of biology, chemistry, and physics leading to the view of earth as a complex system (Schaffer, 2012). In fact, some have argued that earth science engages students in modes of thinking that they will face throughout their lives, for example, the role of narrative logic or making decisions based on incomplete data-sets (Frodeman, 1995). Engaging students in earth science gives them a foundation for thinking critically about large-scale environmental issues like global climate change and natural hazards such as tsunamis and earthquakes (Duschl, 2011; NRC, 2012).

The importance of earth science education for understanding and addressing societal problems is also mentioned in The Geological Society of America's position statement as:

> Basic knowledge of Earth science is essential to meeting the environmental challenges and natural resource limitations of the twenty-first century. It is critical that Earth-science education begins at the kindergarten level and includes advanced offerings at the secondary school level, and that highly qualified Earth-science teachers provide the instruction. GSA recommends that the study of Earth science be an integral component of science education in public and private schools at all levels, from kindergarten through twelfth grade. (Geological Society of America, 2011)

Due to growing recognition of the relevance to issues including climate change, natural hazards, and water and mineral resources, earth science content has been increased noticeably in recent US educational standards documents (NGSS Lead States, 2013; NRC, 2012).

This paper attempts to understand how we can equip future teachers with an understanding of some of the practices of earth science so that they can design effective instruction that engage middle school students in these practices. First, we will explain the domain-specific practices of earth scientists and will compare and contrast these practices to the domain-general definitions of scientific practices. Second, we will summarize the literature on preservice teachers' learning of twenty-first-century skills that will frame the conceptual background of this study. Finally, we will present data on preservice teachers' conceptualization and implementation of scientific practices in the context of earth science content, specifically plate tectonics.

Practices of the Field of Earth Science

The *Framework for K-12 science education* (NRC, 2012) and *NGSS* (NGSS Lead States, 2013) list eight practices that are common across the domains of science or engineering:

(1) Asking questions (for science) and defining problems (for engineering).
(2) Developing and using models.
(3) Planning and carrying out investigations.
(4) Analyzing and interpreting data.
(5) Using mathematics and computational thinking.
(6) Constructing explanations (for science) and designing solutions (for engineering).
(7) Engaging in argument from evidence.
(8) Obtaining, evaluating, and communicating information.

These practices are encouraged to better support students' understanding of the knowledge construction in science (NGSS Lead States, 2013). Although these practices are used in the earth sciences, the definitions should not be overgeneralized by assuming complete equivalence for every domain of science (Chinn, Duncan, & Rinehart, 2014). Earth scientists engage in these practices in ways that are often different from the subfields of physical sciences such as chemistry and physics that predominantly take place in laboratory settings. For example, many earth scientists engage in practices (3), (4), and (7) in much different ways from strictly laboratory scientists given the large spatial and temporal scales of many of the questions asked by earth scientists (practice 1).

About a century ago, the prevailing scientific culture equated science with 'physics' and other fields were referred to as 'stamp collecting' (Dott, 1998). Since then, earth science has been criticized by some from the domains of science that work nearly entirely in laboratory settings for: data-sets that do not completely characterize a study system (due to complexity), lack of experimental control, and the great span of time required for geological processes to take place (Frodeman, 1995). While some philosophers of earth science describe earth science as derivative of physics in the sense that the laws of physics are used to analyze the Earth, they also argue that earth science has a 'unique mode of reasoning' and unique laws of its own (Dott, 1998; Frodeman, 1995). Earth scientists utilize a variety of data and approaches to understand the earth. They use both timeless quantitative data like mathematical and computational thinking practices and time-bound data where they search for and interpret the incomplete historical, descriptive data (Dott, 1998). '[H]istorical based explanations emphasize the differences between geology and physics, which is primarily focuses on establishing time invariant laws' (Dodick & Orion, 2003, p. 208). In contrast to physics, much of earth science investigation is historical and answering many earth science questions requires knowledge of antecedent conditions, for example, the current geology of eastern North America can only be fully understood when taking into account that North America and Africa were joined as part of Pangaea, the last supercontinent, until ~200 million year ago when Atlantic Ocean began to form and split them. One of the goals of earth science is 'to chronicle the particular events that occurred at a given location' (Frodeman, 1995, p. 965). As a result, many earth science hypotheses are not testable in the same way that they are in the laboratory-focused sciences. The limitations of laboratory testing do not allow for experiments sufficient to fully replicate the geological events that happened throughout earth history.

Earth scientists use both retrodiction and postdiction to analyze the causes of past events (e.g. formation of oil and gas resources in the Gulf of Mexico) and prediction about what may happen in the future (e.g. how Earth's climate may change in response to rising atmospheric CO_2 concentrations as a result of fossil fuel combustion). They approach retrodiction and prediction with distinctive characteristics of earth scientific reasoning. The hermeneutic (interpretative) nature of geological reasoning plays an important role in connecting the data from the past and predictions of the future. Frodeman (1995) explains the term hermeneutic as a:

> theory of interpretation; hermeneutics is the art or science of interpreting texts. A text (by which is meant, typically, a literary work) is a system of signs, the meaning of which is not apparent but must be deciphered. This deciphering takes place through assigning differing types or degrees of significance to the various elements making up the text. (p. 962)

Earth scientists who study earth history must determine and read significant elements of the geological record, including chemical and physical evidence from that record, and assemble those elements into a coherent argument explaining past events. Over the last few decades, those arguments and explanations are often supported with computational models such as global climate models. In earth sciences, the practice of 'analyzing and interpreting data' requires understanding data from the geological record to make future predictions. Moreover, object and spatial visualization (e.g. mentally unfolding rock layers, identifying rocks and minerals) are crucial skills for the analysis and interpretation of geoscientific data (Kastens, 2010).

With its interpretive and historical nature, argumentation is an integral practice in the earth sciences. Trend (2009) confirms argumentation as an appropriate framework for teaching earth science. First, many earth science topics are 'socio-scientific' where we are witnessing the argumentation (scientific or non-scientific) through media or in our communities. Second, the nature of natural artifacts (e.g. rocks, minerals) from earth science observations make it possible for teachers and students to directly observe evidence that is tied into larger scale earth systems and processes. Third, many measurements are at scales measurable in the classroom (e.g. cm, grams) as opposed to the scales required in other fields such as space sciences. However, the singularity and the complexity of the geological events in history make the argumentation process more challenging. Extensive earth science collaboration among teams of people, institutions, organizations, and countries in the form of argumentation has led to major theories like plate tectonic theory (Oreskes, 2001). In summary, we can see that earth science uses the same eight practices listed in NGSS; however we can avoid the overgeneralization of the definition of these practices by describing the specific use of these practices in earth science.

Preparing Twenty-first-Century Teachers to Teach Scientific Practices

The recent standards documents (NGSS Lead States, 2013; NRC, 2012) have implications on how future educators should be taught and how teaching should be modeled for them. As we have discussed previously, we now have a focus on different domains of science and their unique practices of doing science. These practices are vital for students' experiences of authentic science in their classrooms. Teachers are now responsible for teaching these practices to help students achieve twenty-first-century skills that are (Partnership for 21st Century Skills, 2004):

- Critical Thinking and Problem-Solving, for example, effectively analyze and evaluate evidence, arguments, claims, and beliefs; solve different kinds of non-familiar problems in both conventional and innovative ways.
- Communication, for example, articulate thoughts and ideas effectively using oral and written communication skills in a variety of forms and contexts.
- Collaboration, for example, demonstrate ability to work effectively and respectfully with diverse teams.
- Creativity and Innovation, for example, use a wide range of idea creation techniques to create new and worthwhile ideas.

Given the focus of the new standards on scientific practices in the USA to make classroom learning more authentic and meaningful, teachers need support in understanding the twenty-first-century skills that are expected in science classrooms (Windschitl, 2009). This support is particularly important since those educating preservice teachers assume that they develop a practical understanding of how to do science when they are out of their teacher training programs (Windschitl, 2003). This assumption was uncovered by Windschitl (2004) when he wanted to understand the influence of 'folk theories' in preservice teachers' conceptualization of inquiry. He defines folk theories as 'presupposed, taken for granted theories about the world that are widely shared by most members of a society' (p. 482). Such theory can be about teaching, as the teacher will fix students' misconceptions instead of guiding them to explore and figure out scientifically acceptable ideas or about scientific practices like learning is collaborative. These theories may develop through preservice teachers' experiences in their middle and high school science laboratories and daily experiences. According to Windschitl (2004), these folk theories play an important role in preservice teachers' conceptions and implementations. Involving teachers in inquiry processes that we target for the science classrooms may not be enough to improve their ability to use the inquiry approach and integrate scientific practices in their classrooms. When we are expecting teachers to understand and adopt the requirements of teaching science meaningfully and effectively in the twenty-first-century classrooms, we may neglect to account for the beginner's repertoire and folk theories they brought into their learning environments: their teaching methods courses, internships, college science laboratories, and education theory courses (Windschitl, 2004; Windschitl, Thompson, & Braaten, 2009) and which they then pass along to their students.

In order to support preservice teachers' development in new practices of science education and determine their conceptual challenges, video case reflections on teaching practices are effectively used and reported in the field of science education (e.g. Chen, Schewille, & Wickler, 2007; Finn, 2002; Sherin, 2000). These reflections can help preservice teachers evaluate their practice in relation to what they have learned in their teaching methods classes. Thus, reflections can help preservice teachers achieve knowledge-based reasoning about their teaching practices (Sherin & van Es, 2005). Moreover, video case reflections can help preservice teachers to identify their challenges during implementation of newly learned teaching techniques (Sezen-Barrie et al., 2014).

In this study, we want to understand the practices that preservice teachers choose to employ in teaching practices of earth science for the case of three lessons on plate tectonic theory. Then, we draw conclusions on how these practices can be relevant to folk theories of teachers (i.e. what practices these teachers might be familiar with in their history of learning and teaching). Moreover, we report on the challenges that teachers face in implementing newly learned teaching methods as mentioned in their written video case reflections. This study sees training preservice teachers as an important step for the implementation of these activities in future science classrooms. Therefore, the study answers the following research questions based on the observations of preservice teachers enrolled in the middle school science program.

(1) Which scientific practices do preservice teachers integrate into their microteaching experience on plate tectonic theory?
(2) What challenges do preservice science teachers face in teaching about plate tectonic theory while focusing on scientific practices?

In the USA, plate tectonic theory is one of the core scientific concepts recommended in both the 2012 NRC K-12 framework document (#ESS2.B) and College Board Standards for Success (2009) in Science (#ES.1.3). These documents emphasize that learning plate tectonics is expected to improve the scientific practices of analyzing and interpreting data based on their observations of maps and argumentation around the evidence based on data. Research on students' understanding of maps emphasizes that they have difficulty reading maps in science classrooms (e.g. Lehrer & Pritchard, 2002; Liben & Downs, 1993). Reading maps, however, is an important part of earth scientists' work and thus an important scientific practice that students need to learn to make sense of the work of an earth scientist. Argumentation, another common practice of scientists, is rarely observable in science classrooms because teachers feel uncomfortable asking students to employ data to argue scientific ideas (NRC, 2007a).

Methods

In order to respond to the research questions, this study is designed as a qualitative, exploratory case study of seven preservice teachers as they are learning to teach plate tectonic theory.

Educational Context

Participants. The study was conducted during the Fall/Autumn 2012 semester as a part of a science teaching methods course for middle school majors in a program preparing teachers for teaching science in grades 4–8 (ages 9–14 years). The participants were seven preservice teachers (five female, two male) who are in their senior/fourth and final year at a public university in the mid-Atlantic USA. At the time of the study, most of the preservice teachers were ages 21 and 22 years. These preservice teachers study toward earning double majors in middle school education. Five of seven preservice teachers were in Mathematics and Science majors, whereas the rest is in Social Sciences and Science majors. The participants who were Mathematics and Science majors had not taken any Geography or Geosciences courses in college. Other two participants were in social-science and science double major took a physical geography and learned about plate tectonic theory during two or three class periods (each 55-minute long). Prior to the science teaching methods course participants had no teaching experience in science and a very limited experience in observing science lessons. None of these observations of practicing middle school science teachers was on earth sciences.

In order to increase the collaboration of preservice teachers with practicing middle school teachers, the university course met in a classroom inside the middle school. The middle school in this study served grades 6–8 (ages 11–14 years) and is located in a suburban area of mid-Atlantic region of USA. The demographic of the school 46.6% White, 38.7% African-American, 6.8% Hispanic or Latino, 3.23 Asian, 0.60% Native American, 0.03% Pacific Islander, 0.86% from other races, and 3.18% from two or more races. The typical class size at this middle school is 24. Recently, the middle school encourages integrated Science, Technology, Engineering, and Mathematics programs where science and mathematics teachers invite practicing scientists and engineers to support students' science projects.

Learning activities. During the university course, the methods instructor arranged presentations and activities on effective teaching methods of scientific discourse and practices, question and answer sessions with preservice middle school science teachers, and classroom observations and microteaching activities (teaching to groups of 5–6 students). This study focuses on the weeks when preservice teachers were learning to teach unique practices of earth science and practicing their learning in a microteaching assignment. In our study, we defined microteaching as a teaching activity designed for a small group of students (five or six students per group). Each preservice teacher was responsible for teaching to only five or six students from a seventh grade classroom where the students are ages 12 or 13 years. By focusing on only a small group of students, preservice teachers were given a more controlled environment in which to learn how to teach the practices of earth science blended with the scientific background behind plate tectonic theory. The Project Investigator (PI) (science education researcher) and co-PI (earth science researcher) developed or modified four exercises to give preservice teachers proficiency in using earth science practices and help them learn plate tectonics.

First, to develop student skills in observation and interpretation to reconstruct historical events, students engaged in an activity entitled 'Differentiating Observation vs. Interpretation.' We used a story and a drawing from the US Geological Survey called 'GeoSleuth Murder Mystery.' Preservice teachers attempted to solve the murder based on clues from the story and drawing. They were then asked to relate the activity to how earth scientists observe, interpret, and place in sequence events to draw conclusions (Figure 1).

Second, in order to engage students in the scientific practices and collaborations involved in the historical development of the plate tectonic theory, preservice teachers were assigned chapters from *Plate Tectonics: An insiders' history of the modern theory of the earth* (Oreskes, 2001). The reading assignments were followed by class discussion sessions where preservice teachers chose 10 important messages from the book.

Third, in order to support preservice teachers' use of evidence, the methods course instructor introduced KLEW Chart as a supportive instructional framework. KLEW Charts start with a question of 'What do I Know? (K)' to understand the

Figure 1. GeoSleuth murder mystery drawing
Source: Image courtesy of M.A. d'Alessio and the U.S. Geological Survey

prior knowledge of students. Then two further questions follow: 'What Have I Learned? (L)' and 'What is my Evidence? (E)'. It is important that the teachers guide students to explain their learning with evidence. At the end of the activity, the chart asks students: 'What are You Wondering? (W)' in order to encourage students to talk about their further questions on the topic (Hershberger, Zembal-Saul, & Starr, 2006).

Fourth, we used a data-rich exercise 'Discovering Plate Boundaries' with the goal of engaging preservice teachers in observation, analysis, and interpretation of the data on the maps in an effort to understand the Earth's plate boundaries (Sawyer, Henning, Shipp, & Dunbar, 2005). The real data in Sawyer and his colleagues' exercise come from the Smithsonian Institution in DC, Incorporated Research Institutions for Seismology, University of Sydney, Australia, and US National Geographical Data Center. Figure 2 shows the maps we used in our activity: (a) Seafloor Age, (b) Earthquake location and depth, (c) Location of recent volcanic activity, and (d) Topography and Bathymetry.

Data Sources

Four types of data were collected in this study. First, preservice teachers were video recorded while learning of earth science content, that is, playing the 'Murder Mystery' activity and discussing their understanding of the book, *Plate tectonics: An insiders' history of the modern theory of the earth* (2001). The researcher also took notes during these activities. Conversations were transcribed from video records of these activities for further data analysis. Second, data were collected on how preservice teachers learn to teach. Preservice teachers' microteaching of plate tectonics to a group

(a)

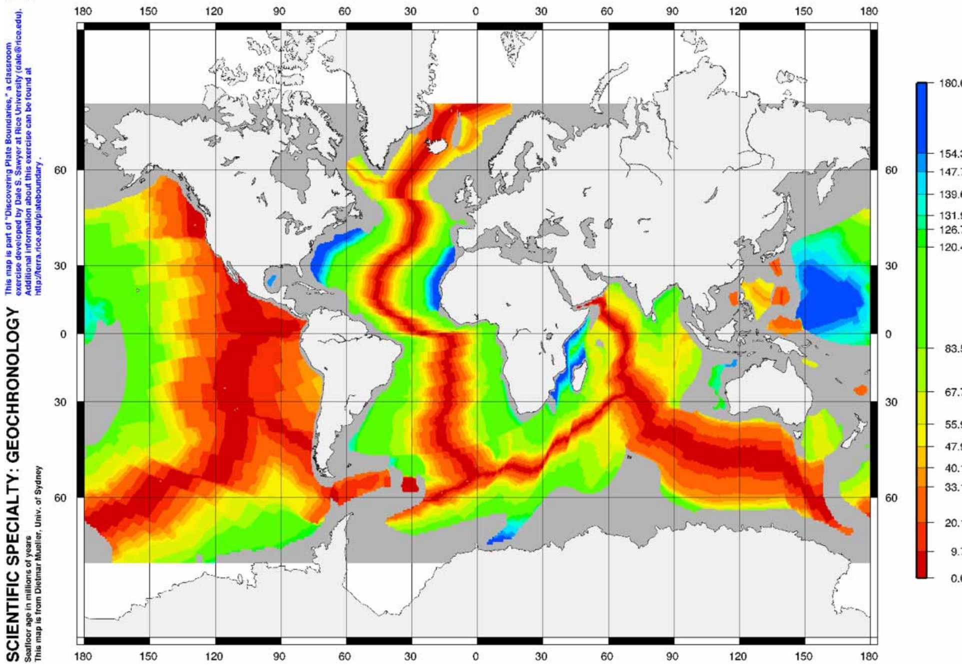

Figure 2a. Data maps used during the ‘Discovering Plate Boundaries’ activity: (a) Seafloor Age, (b) Earthquake location and depth, (c) Location of recent volcanic activity, and (d) Topography and Bathymetry
Source: Sawyer et al., 2005

of students in three 50-minute long lessons was video recorded. Ten-minute segments were selected and transcribed to analyze how preservice teachers used scientific practices. The third source of the data was the set of artifacts produced before and during teaching of plate tectonics (e.g. lesson plans and worksheets prepared to use during microteaching events). The fourth source was preservice teachers’ written reflections produced after the microteaching event.

Analyses and Findings

To answer our first research question on which scientific practices preservice teachers integrate as they are using real data, we used intertextual discourse analysis. Intertextuality is one of the theoretical tools of discourse analysis. Gee calls intertextuality ‘when one text (in this sense) quotes, refers to, or alludes to another text (that is what someone else said or wrote), … ’ (2011, p. 165). In our study, the texts we used were the readings on the history of plate tectonic theory, the videotaped discussions on readings, preservice teachers written comments as they were involved in murder mystery activity, and videotaped interpretations of preservice teachers working on plate boundary maps. Then, we correlated these texts with their lesson

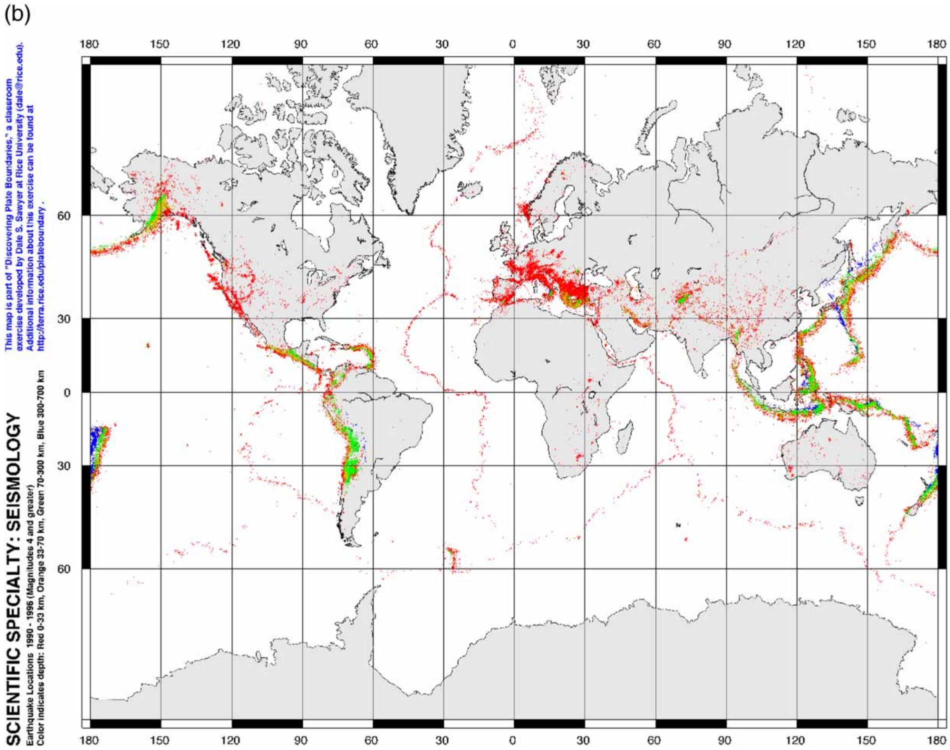

Figure 2b. Continued

plans, microteaching events, and written reflections. In other words, we searched for the practices of earth science that preservice teachers learned in the transcripts of their teaching as well as in the artifacts produced.

The lesson plans and transcriptions of microteaching experiences showed four areas that were also emphasized in the texts. We considered that preservice teachers in our study chose to focus on these four practices: (1) employing historical understanding of how the theory emerged, (2) encouraging the use of evidence to construct a theory, (3) observation and interpretation of models, and (4) collaborative practices inform theories.

In their reflections, all preservice teachers stated that the use of real data was helpful in engaging students into the practices of earth science; however this experience brought up some challenges for the first time teaching of the content. In order to understand the common challenges faced by seven preservice teachers, we used constant comparative analysis (Strauss & Corbin, 1990). For this analysis, we broke written reflection into individual utterances. An utterance, in our study, is a unique idea or contribution to the discussion. A code that represented the functions of an utterance served, or the meaning it conveyed in the text, was assigned to each utterance. The codes are then categorized under each of the four scientific practices that preservice teachers employed in their microteaching or lesson plans. For example,

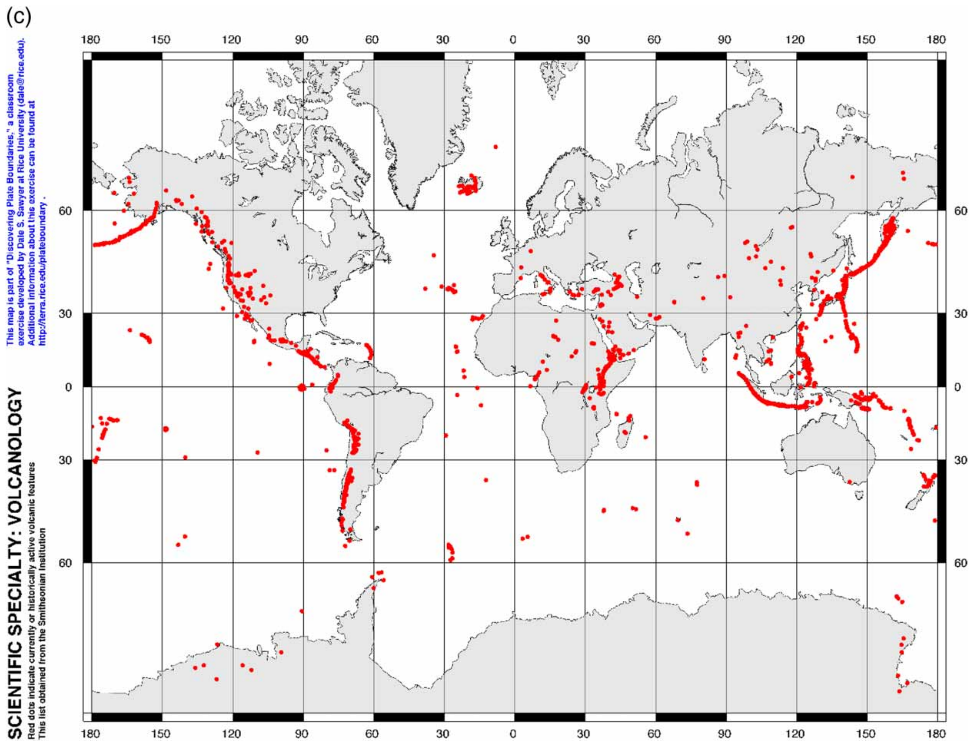

Figure 2c. Continued

in preservice teacher Brittany's written reflection, one of the utterance was 'However, students were having hard time relating evidence to plate boundaries' and it was coded as 'evidence-claim disconnection'. In another instance from preservice teacher Sam's written reflection 'it was hard to see evidence for different boundary types' and it was coded 'observing evidence'. Both of these codes later categorized under one of the focused practices, 'encouraging the use of evidence to build up a theory'.

At the end of our analysis, the scientific practices that preservice teachers integrated into their microteaching experiences are classified into four main categories (Research Question #1) and the challenges that they experienced are categorized into these four categories (Research Question #2). We will examine student responses using these four categories in the context of the four cases below to explain how preservice teachers integrated the practices of earth science and what challenges they faced during these implementations. For each category, we will explain the *source* to refer to the text where preservice teachers heard, learned, or experienced the idea; *observed* to refer to what is seen in the lesson plan and microteaching; *reflection* for quotes from preservice teachers' written reflection. To protect the privacy of our participants, we will use blind names for our preservice teachers.

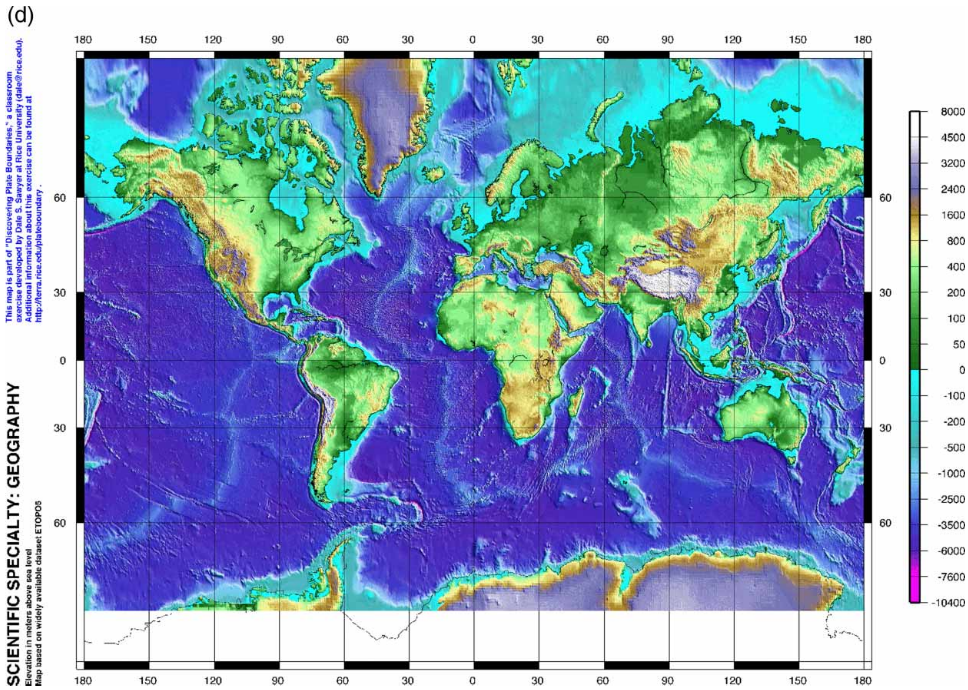

Figure 2d. Continued

Historical Understanding of How the Theory Emerged

One practice observed in microteaching experiences is that preservice teachers tried to help students understand the historical development of theories, specifically, the ideas that lead to the emergence of plate tectonic theory. Although all branches of science utilize the historical development of ideas for the background of their study, earth science gives special attention in understanding the historical nature of data to make interpretations. Table 1 shows that preservice teacher Rachel paid attention to plate tectonic theory being 'influenced by the ideas of the ideas of scientists before 1960s' from her reading of *Plate tectonics: An insiders' history of the modern theory of the earth* (source). Thus, she used an activity to encourage students' understanding of previous theories on continental drift and link this previous theory to her activity on plate tectonic theory (observed in the lesson).

In her reflection of the teaching of Wegener's proposal on 'continental drift', she mentioned a challenge in helping the seventh grade students (ages of 12 or 13 years) understand the definition of a theory. As is seen in the transcript below, Rachel (the preservice teacher) is trying to help students to define 'scientific theory'. However, students' preconceived notion of theories is interfering students' understanding:

Rachel: Remember the scientist, Alfred Wegener? Does that ring a bell?
Students: Yes
Rachel: So when I say theory, what does that mean? Raise your hand.

Table 1. Intertextual analysis of Rachel's focus on history of plate tectonics theory

Source	Observed in the lesson	Reflection
Reading on the history of plate tectonics Transcripts from Rachel's discussion of the reading: *All scientists came up with different approaches and evidences to build up a theory—Plate Tectonics theory. The theory was influenced by the ideas of the ideas of scientists before 1960s. The evidences scientist found is related to their personal experiences*	Rachel uses Pangea puzzle as one of her engaging activities as to have students develop historical understanding of the theory of plate tectonics. When the students mention that there was a huge continent in the past, she asks them *what do you think happened to that huge continent?* and she tried to connect it to Wegener by asking *Do you guys know who came up with that theory?*	Rachel's reflection *A challenge I had was getting them to understand what a theory was. I spent a lot of time trying to help them come to the definition of on their own without me just giving them the answer*

Student: An idea
Rachel: Well maybe it's a little more than an idea. If I had an idea—If I said I have an idea that the sky might not actually be blue, would that count as a theory?
Student: No because it can be proven
Rachel: It can be proven- that the sky is not actually blue? So does a theory mean that it is 100% correct? Even if it can be proven? What makes it still a theory?
Student: It's a prediction. The Big Bang theory.
Rachel: Okay, the Big Bang theory—why was that a theory
Students: Authentic?

The approach to introducing the theory of plate tectonic used by Rachel has the potential to be beneficial. She attempted to guide the students to the definition of a theory through questioning. However, Rachel was challenged in her use of this method by students' preconceived definition of an everyday life theory. Other preservice teachers also faced similar challenges with students' understanding of a theory and its place in nature of science. Thus, this challenge might have created obstacles in understanding the historical development of the idea of plate tectonic theory and what makes it a strong and widely accepted theory with the involvement of many scientists and institutions.

Encouraging the Use of Evidence to Form a Theory

Another practice apparent in the data was that preservice teachers attempted to use argumentation and encouraged students to seek for evidence during the microteaching events. Table 2 shows that Brittany (preservice teacher) used her understanding from the KLEW Chart activity that she learned in the methods course (source) and used this idea to ask students for evidence as they look at their data maps.

The preservice teacher Brittany has effectively used the real data to ask for evidence during her three lessons. However, she did not guide the students toward making any direct claims based on the evidence they saw on the maps. Instead, she moved to a new topic. She presented an array of information to the students without making connections to student responses or their understanding of data (observation).

Brittany: I want to come up with what you think Alfred Wegener thought when he created this theory—some concrete information you can use [when] looking [at] your different types of evidence.
Student 1: They look like they fit together

Student 2: Plants, animals

Student 3: Weeell mountain ranges, fossil records

Brittany: Well his theory doesn't really talk about how they separated. It did talk about we know that it separated because of these different evidences we found.

In effective questioning, it is important to notice students' responses that are relevant to the task and connect those to scientifically accepted explanations (Sezen, 2011). In Brittany's case, we can see that she needs to improve on effective questioning to be able to use argumentation practice. Brittany might also be having difficulty to guide students' ideas due to her lack of background knowledge about the evidence that Alfred Wegener used, such as how mountain ranges form and the habitat needed for certain plants and animals. Studies on effective questioning (e.g. Carlsen, 1991) suggest that stronger subject-matter knowledge will help teachers notice students' responses that are relevant to the scientific ideas.

Observation and Interpretation of Plate Boundary Map

All seven preservice teachers integrated real data into their microteaching experience, meeting the requirements for the assignment. They all wanted to use the evidence

Table 2. Intertextual analysis of Brittany on encouraging the use of evidence

Source	Observed in the lesson	Reflection
Methods Course: Engaging into Argumentation KLEW Chart has been used to support preservice teachers' argumentation during investigations (Hershberger et al., 2006) KLEW Chart: K—What do I know? L—What have I learned? E—What is my evidence? W—What do I wonder?	Asking for Evidence during Microteaching Transcript from Preservice Teacher Brittany: *What kind of evidence are you using [to say these continents were together]? What about these mountain ranges?* *What about you ladies? What kind of evidence did you use to build your map?*	Brittany's Reflection *I think students really enjoyed getting [to] examine real data [for evidence]. They found the information more relevant and were able to relate active areas on the map to current events around the world. However, students were having hard time relating evidence to plate boundaries*

from the data maps to help students observe the location of the plate boundaries as well as recognize the different boundary types. As you see from Table 3, Sam studied the plate boundaries during the 'Reading & Interpreting Real Data' Exercise (source) and then he asked students about the plate boundaries they see on the data maps (Observed in the Lesson) and he describes his strategy of using these maps with students (Reflection).

Despite the benefits of these data maps for teachers using real data in their teaching, we have observed challenges to implementation of earth science practices by preservice teachers. From observations of all preservice teachers' videos, we saw that while the seventh grade students were able to make moderately accurate connections between the data and the theory, they seem lack the geographic knowledge to make real connections.

After students came up with classification of plate boundaries strictly guided by directions given to them, Sam used these classifications to give them an explanation about different types of plate boundaries. At that point students were able to develop relationships between data and the plate boundaries but did not have an understanding on where the plate boundaries existed. Many of the participating students appeared uncertain of the significance of the locations of the boundaries. Moreover, as exemplified in the transcript below between Sam and his students, the reasoning behind students' inaccurate interpretations (They're pushing together) were not investigated. These statements were just corrected by the preservice teacher (Well if they're divergent, they're not pushing together, …). Moreover, we

Table 3. Intertextual analysis of Sam on encouraging observations and interpretations of data

Source	Observed in the lesson	Reflection
'Reading & Interpreting Real Data' Exercise The exercise developed by Sawyer at Rice University was done with the preservice teachers so that they can read the data from four different maps: Seismology, Volcanology, Geography, and Geochronology to understand how they were related to the plate boundaries found on the world map	During the lesson, Sam has different specialty groups working on each map. After Sam helps students engage in the practice of using data to come up with their own classification schemes, he tells students *to trace the activities in their specialty maps to the plate boundary map.* Then he goes to every pair of students and asks *If your tracing matches with the boundaries, what do you think is going on here?* *Are they sliding, moving apart, coming together?* *Make sure to talk with and evidence from your maps*	Sam's reflection *The student pairs were each given a selected map to examine for a few minutes. While in the groups' possession the group instructed to use markers and determine where each plate boundary was, or where the plate boundaries you could identify with the map in front of each group. When each group was finished examining and marking each map, the students then switched counterclockwise and began looking at a different map. While the maps were being passed between groups, the groups were instructed to revise the older groups' finding*

also see that preservice teachers do not ask students to make their own classification purely based on their observations as is originally intended in the data-rich activity. Preservice teachers instead give directions by using scientists' interpretation of these data.

Sam: Can anyone explain to me why the mid-Atlantic ridge is mostly divergent? What do you think? Use your maps?
Students: They're pushing together
Sam: Well if they're divergent, they're not pushing together, they're spreading apart. Can you explain to me why the mid-Atlantic ridge is divergent?
Student: Oh I know why now. Because they're pushing apart and the volcanic—the lava makes the land.
Sam: Okay, so it seeps up? It makes new sea floor? Okay

Students had immense challenges in interpreting the maps and understanding the theory of plate tectonics as well as the specific types of plate boundaries. As the preservice teacher Sam did not focus on students' responses, the class as a whole seemed distracted and off task relatively frequently. This shows us the importance of learning to observing and then interpreting real data to turn them into a valuable lesson for students. Moreover, we also realize that preservice teacher Sam might not be knowledgeable about how volcanoes form along divergent boundaries to guide student's comment about the volcano at the Atlantic Ridge. This lack of content knowledge might also be the reason he could not recognize why students might think plates are pushing together at the Atlantic Ridge. As seen in the transcript from the preservice teacher Sam, lack of subject-matter knowledge can create challenges in guiding students' ideas.

Use of Collaborative Practices to Form a Theory

Data analysis showed that preservice teachers encouraged collaborative work to explain the importance of strong teamwork in theory making. Every preservice teacher engaged their students in at least some collaborative work during their microteaching, but Emma successfully employed variety of strategies to do so. As is seen in the analysis below, she focused on a point on 'Global Synthesis'—merging of scientific fields and ideas' in our discussion of the book *Plate tectonics: An insiders' history of the modern theory of the earth* (source). She used a role-playing activity where she assigned students to different fields that provided evidence for the plate tectonic theory and emphasized student roles by giving them badges with their new scientist identities (Observed in the Lesson). The summit she created among different fields encouraged most students to participate and present their data (reflection) (Table 4).

Preservice teachers did not mention any significant challenges, nor were any observed by the researcher, in using collaborative work activities. The only concern with these activities was the group dynamics, which did not completely impede the implementation of the activities.

Table 4. Intertextual analysis of Emma on using collaborative practices

Source	Observed in the lesson	Reflection
Reading on the history of plate tectonics Transcripts from Emma's discussion of the reading: '*Global Synthesis'—merging of scientific fields and ideas.* *Overlapping ideas can lead to full understanding of earth science*	Collaborative processes in making up theories From Emma & Quinn's lesson plan while introducing the four fields involved in the development of the plate tectonics Theory *Students will be grouped into 4 groups by playing four corners: Each group will have a volcanologist, a seismologist, a geochronologist, a geographer. Together the expert groups will determine what their data means and record in their section of the graphic organizer*	Emma's reflection *I told the students that we are going to role play being specialist in the field of science …* *Lastly, we started the summit. We announced that we are now entering the summit and asked that everyone display his, her badges. This was something they seemed to really enjoy. Each group went in turn, and presented [their data maps]. Each group presented and three of the four did well*

Conclusions and Implications for Preservice Teacher Education

NRC's report on *Taking science to school* made an important point by stating that 'The recurring activities in science classrooms offer entrée to a narrow slice of scientific practice, leaving students with a limited sense of science and what it means to understand and use science' (2007b, p. 254). In order for students to experience the authentic nature of science, *Framework for K-12 science education* (NRC, 2012) and the Next Generation Science Standards (NGSS Lead States, 2013) in the USA emphasize teaching core scientific ideas through engagement in scientific practices. Earth science has its unique practices developed by the community of earth scientists (Frodeman, 1995) and its own discipline-specific criteria for excellence in inquiry (Ault, 1998). Moreover, many earth science topics are socio-scientific in that controversy in public opinion might create tension in science classrooms. Since earth science has its unique reasoning and procedures and its content tends to be socio-scientific, it is especially crucial to provide a data-integrated environment and teacher guidance to support student understanding of these practices.

In this study, preservice teachers utilized a microteaching environment where they focused on a small group of students. Although this is not a representation of real classroom environment, microteaching helps preservice teachers to focus on teaching content and practices by removing some of the challenges of classroom management. This environment is especially useful when preservice teachers are experiencing teaching for the first time (Sezen-Barrie et al., 2014).

We explored how plate tectonic theory is taught in a data-integrated environment and other exercises supported by variety of sources. Through intertextual discourse analysis of preservice teachers' discussions, artifacts, microteaching videos, and written reflection, we identified the earth science practices that the preservice teachers adopted, how their previous experiences, readings and exercises influenced their learning process, and the challenges they faced in implementing those practices. Commonly used practices by the preservice teachers in this study were (1) historical understanding of how the theory emerged, (2) encouraging the use of evidence to form a theory, (3) observation and interpretation of models, and (4) collaborative practices to form a theory. Preservice teachers had challenges in implementing these common practices with the exception of the collaborative practices in making up the theory. All preservice teachers experience collaborative learning environments in their college courses and they all have experience in developing collaborative activities for their education courses. As a result, we claim that the effectiveness of earth science practices used by preservice teachers was determined by (1) what is new to teachers and (2) their personal history in understanding teaching practice and how science works, that is, their folk theories of teaching and earth science discipline. Therefore, we suggest a more in-depth study in understanding the folk theories developed by preservice teachers about practices of science, generally, and earth science, specifically.

Studies of misconceptions related to plate tectonic theory show that students have challenges connecting plate motions with observable processes such as earthquakes and volcanoes (Smith & Bermea, 2012). These challenges were also evident in our study as is seen in Sam's (preservice teacher) transcript while he was trying to encourage students to find convergent and divergent boundaries in seismology and volcanology maps. We observed that preservice teachers' use of effective questioning strategies to recognize student ideas and alternative conceptions was missing as is seen in other studies of science education (Hogan, Rabinowitz, & Craven, 2003). It is important to note that preservice teachers' inability to guide student understanding and giving them the correct response impeded students' conceptual development. We also note that lack of subject-matter knowledge in the areas of topography, volcanology, seismology, and geochronology might create challenges for preservice teachers. One example is seen in Brittany's difficulty in guiding students' ideas because of her lack of understanding on how mountain ranges form and geographical conditions for specific plant and animal lives. Another example was Sam's difficulty in recognizing why students might be misinterpreting the type of plate boundary at the mid-Atlantic ridge due to lack of understanding of how volcanoes form along divergent plate boundaries. Thus, we suggest that preservice teachers need better preparation to improve their subject-matter knowledge in different fields related to earth science to be able to implement related pedagogies such as effective questioning strategies. These effective questioning strategies will help preservice teachers in guiding their students' engagement into the practices of earth science.

Although preservice teachers learned about plate boundary processes in one of their courses prior to this teaching experience, this learning experience should be grounded in learning in other science courses. Furthermore, we suggest that preservice teachers should understand the cultural–historical construction of knowledge by scientists in the field. For example, they should learn how these scientists created the data maps, what are the norms of representing data in each field and how different fields can combine their representations in one visual tool. We suggest that college courses where preservice teachers can establish this background should be rearranged to integrate scientific practices and the key reasoning patterns while teaching novel scientific ideas. An example to integration can be having combined laboratory and lecture courses that will help students to understand how the knowledge they learn in the lecture is constructed. This can protect our teachers from rote memorization (Ford, 2008).

Vocabulary is an important part of classroom learning and it takes a special form in science. Some words might have very specific meaning in a scientific context that is quite different from their daily usage (NRC, 2007a). In our example analysis from Rachel, we realized that she was challenged by students' layman definition of the word 'theory'. Therefore, we should prepare preservice teachers to help students develop an effective scientific discourse during their teaching.

Although preservice teachers encouraged students to use evidence, the arguments did not have a strong epistemic quality, that is, students did not attempt to explain, interpret, or connect the evidence to general theory (Sandoval & Millwood, 2005). This shows that preservice teachers need extensive support in helping students develop their argumentation practices. Science education researchers have worked on effective methods to improve preservice teachers' argumentation practices (e.g. Erduran, Ardac, & Yakmaci-Guzel, 2006; Zembal-Saul, Munford, Crawford, Friedrichsen, & Land, 2002), but we noticed that argumentations by using data maps as a source of evidence is rare (Kelly & Takao, 2002) and does not focus on preservice teachers. We suggest more studies on preservice teacher argumentation by using the inscriptions from the field of earth science are also necessary.

In our analysis of lesson plans and microteaching videos, we did not see any evidence that preservice teachers helped students to differentiate their observations from their interpretations. Although these preservice teachers effectively participated in the murder mystery activity from the USGS and discussed the difference between observations and interpretation in looking at different rock types, they chose not to focus on this earth science practice in their plate tectonics lessons. This might be related to their folk theories of how science works (e.g. they might have already theorized that scientific observations do not leave room for interpretations), as they may not have observed this practice commonly in their own schooling or observations of middle school science teachers. Moreover, interpreting data requires higher level of epistemic practice than just stating the observations (Kelly & Takao, 2002) and thus preservice teachers might not have felt comfortable using this practice with middle school students.

> The Earth is the only world known so far to harbor life. There is nowhere else, at least in the near future, to which our species could migrate. Visit, yes. Settle, not yet. Like it or not, for the moment the Earth is where we make our stand. (Sagan, 1997)

This quote, made right as Voyager I left our solar system forever, reminds us of our responsibility to the pale blue dot that is Planet Earth—the only home we have. As science educators, we have a responsibility to help preservice teachers understand Earth by supporting their comprehension of the major theories of Earth Science. Given the increased emphasis on Earth Science in the new standards documents, we should explore ways to more effectively prepare the preservice teachers who will pass on their learning to future generations. The theory of plate tectonics is perhaps the key undergirding theory of earth science and provides an essential background to understanding other earth science concepts. In this paper, we focused on one of the critical earth science core concepts—tectonic plate boundaries—because 'a significant portion of the world's population lives near plate boundaries' (Sawyer et al., 2005, p. 73). Learning about the processes that occur at plate boundaries will help future teachers (and their students) understand natural disasters such as earthquakes and volcanoes. Because these disasters can affect the daily lives of a major portion of the world's population, it is important for every student, whether they pursue a science career or not, to be knowledgeable about plate tectonic processes (Sawyer et al., 2005).

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