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Developing A Hypothetical Learning Progression for Plate Tectonics

1. Subject/Problem

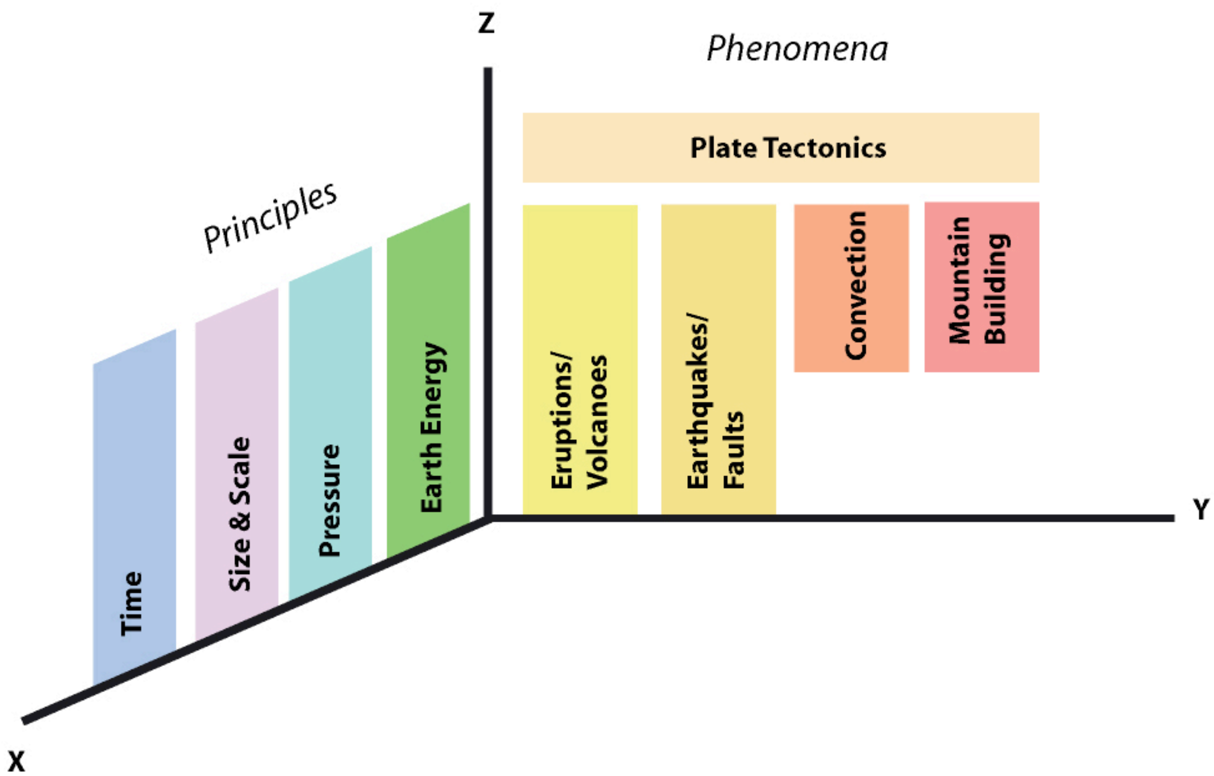
Plate Tectonics is an organizing principle in Geosciences. Current Earth and Space Science teaching, like almost all teaching in science (Kesidou & Roseman, 2002), is not organized in a way that reflects this organizing principle and instead focuses on memorization and fails to help students make conceptual connections between individual phenomena, such as earthquakes, volcanoes, and mountain building. The *Framework for K-12 Science Education* (NRC, 2012), recommend that teaching focus on big ideas, as well as the practices of science, in order to help students develop more productive understandings of science content and the way science works as a discipline.

Learning progressions have been proposed as a way to capture how students' understandings develop within big ideas of science over multiple grade levels or years. These big ideas describe unifying concepts that help make sense of a broad variety of phenomena, offering robust explanatory power for the world around us (Smith et al., 2006). Learning progressions can then be used to guide the developing of curriculum as well as supporting innovative teaching practices around those big ideas (Alanzo & Gotwals, 2012; Corcoran, Mosher, & Rogat, 2009). There is still significant discussion in the field about how to design, represent, revise, and validate learning progressions in science; however, there is overall agreement that learning progressions describe how students may grow in sophistication towards a *big idea* in science (e.g. Corcoran et al., 2009; NRC, 2007). A learning progression describes how intermediate levels of sophistication can be productively built upon, rather than focusing simply on eliminating alternative ideas in favor of normative scientific ideas. In addition, learning progressions describe how instruction can support students' developing understandings across multiple grades or years, though breadth of the progression and the grain-size of analysis vary between research groups and topics.

Plate Tectonics is the focus of the learning progression research reported here. The choice of Plate Tectonics as a big idea in Earth and Space Science is an obvious one, as it is the organizing principle for the phenomena that are driven by the energy systems of the interior of the Earth (e.g. earthquakes, volcanoes, and mountain building). While Plate Tectonics is clearly identified as a big idea in science (e.g. ESLI, 2010; NRC, 2012), there has been little research focused on understanding student thinking in this area. This may be because the underlying understandings of geologic time that are required (Dodick & Orion, 2003) make conceptual understandings difficult. It may also be that the reliance on diagrams and maps, and thus the interpretation of two dimensional representations of three dimensional phenomena, makes this a difficult area for students (Gobert, 2005; Gobert & Clement, 1999). In any case, such a critical big idea in Earth Science will benefit from the development of a learning progression to help guide teaching, curriculum development, and assessment.

To build a complex learning progression around principles and phenomena, we have adopted a framework of building a learning progression by examining progress in multiple dimensions (C.

Anderson, personal communication) that combine to form an explanation for Plate Tectonics. This process is similar to building learning progressions from multiple *construct maps* – each possessing an upper and lower anchor and levels of increasing sophistication (Wilson, 2009). Figure 1 illustrates the dimensions of the learning progression: constructs on the x-axis are generalizable to broad areas of science (Earth energy, pressure, size and scale, and time); constructs on the y-axis are



contextualized in Plate Tectonics phenomena (earthquakes/faults, eruptions/volcanoes, convection, and mountain building). Progress is measured in each dimension up the z-axis. While any one of these dimensions can be analyzed individually, development towards an integrated understanding of Plate Tectonics requires the student to make connections between the dimensions over time. Our goal is to understand how students progress through the 3-dimensional space of this learning progression.

Figure 1. The x- and y-axes show dimensions of progress in scientific principles and phenomena associated with understanding solar system formation. Students' progress can be mapped by their location in the 3-dimensional space described by these axes. *This diagram is only a representation of the dimensions of the learning progression, not a full learning progression.*

2. Design/Procedure

This research project was part of a larger National Science Foundation funded Math Science Partnership grant. The Earth and Space Science Partnership focuses on improving students' understanding of big ideas in middle grades Earth and Space Science. The research drew on students in partner districts across the Commonwealth of Pennsylvania, which included urban (Philadelphia, Reading, and York City), suburban (State College) and rural (Bellefonte, Bald Eagle and Penns Valley) school districts. Students from middle school (6th grade) and high school (9th – 12th grade) were interviewed (N=41). The interviews were open-ended and conceptual, focused on eliciting students understandings around the core three phenomena: earthquakes, volcanoes, and mountain building. In addition, there were questions explicitly focused on Plate Tectonics.

The analysis of interviews was completed by an interdisciplinary team of educational researchers (one faculty member, a post-doctoral scholar, and one graduate student) and geoscientists (two faculty members, a post-doctoral scholar, and one graduate student). This allowed us to make adjustments to the codes and the emerging dimensions in terms of both learning theory and normative scientific understandings.

Analysis of interviews focused on the identification of dimensions of the learning progressions as well as examining student responses for evidence of the use of underlying principles. In an iterative process of coding the interviews, initial codes were defined from a subset of interviews then applied to additional interviews, with new codes added and old codes refined as needed to capture students' thinking. Once this system of categories and codes had been applied to the interviews, we looked ways to sort students' ideas, along each dimension with a goal of highlighting those aspects of students' thinking that moves them in productive ways towards the scientific idea. We used this analysis to begin outlining levels of increasing sophistication along each dimension. We also looked for connections between dimensions by: 1) considering how students would need to bring multiple dimensions together to form more sophisticated explanations, based on the analysis of the discipline, and 2) looking for patterns in how students naturally made connections between the dimensions.

The findings reported here are the result of both the analysis of student responses as well as a discussion by the research team of how students' ideas might progress given a different structure of curriculum and teaching. This was necessary as students' ideas were very often superficial and unproductive, thus at this point in the research the learning progression is largely hypothetical.

3. Analyses and Findings

We begin by characterizing the principles and phenomenon that make up the dimensions along the x and y axis in figure 1, our representation of the hypothetical learning progression. First, the phenomena along the y axis: earthquakes/faults; eruptions/volcanoes; convection; mountain building. Earthquakes and volcanoes are typical topics in an Earth Science curriculum and were chosen for this purpose. The other two phenomena are more typical of the way geoscientist conceptualize the phenomena that are connected to Plate Tectonics. Convection drives much of the dynamic Earth, and is critical to understanding all the core phenomena of Earth Science. Mountain building, while it may be a topic in K-12 science teaching, is not usually addressed in a way that supports understanding the phenomenon's relationship to Plate Tectonics; however, it is intimately connected to volcanoes and earthquakes via Plate Tectonics and is critical to understanding much of the surface geology.

The x axis consists of the scientific principles that cut across the phenomena and provide conceptual connections that can be built upon by teachers to help students make linkages between the dimensions of phenomena. The first, Earth energy, was chosen based on the way geoscientists talk about phenomena in the field, in the sense that they differentiate between processes that are powered by solar energy, e.g. erosion as a result of the water cycle, and processes that are powered by Earth energy, e.g. convection. Earth energy includes the residual heat from the formation of the planet and the heat generated internally by radioactive material in the Earth, as well as strain energy stored in minerals undergoing deformation. This differentiation between energy systems is an important distinction and one that is largely absent in the way K-12 Earth Science is taught or conceptualized. Pressure is a principle that we know to be important to Earth Systems Science and we anticipate more of a focus on this area as our work develops. The last two principles along the x axis constitute two areas that we know are existing conceptual issues in understanding Plate Tectonics. Deep time and large spatial scales are difficult for students to understand (Dodick & Orino, 2003) and we recognize that these areas will be potential points of intersection with learning progression work our group is doing in solar system formation. Thus, these two dimensions are included with an anticipation of evolving focus as the research continues.

Figure 1 is the result of the analysis of student interviews and discussion among the educational and geoscience researchers in the team. Therefore, they represent initial findings in the form of dimensions of a hypothetical learning progression. To understand how the findings impacted the creation of figure 1 we will now discuss some of the finding in detail.

The interview finding that most impacted the hypothetical learning progression was the recognition that students explain phenomena that are driven by Earth energy in the context of solar energy processes. For example, students commonly indicate that volcanoes happen in warmer climates or that depositional rock layers building up over time will lead to earthquakes. This recognition led us to define an early level in the learning progression as the ability to differentiate phenomena that are caused by the two different energy systems. This approach is a significant break from the way K-12 ESS thinks about/teaches these topics, as Earth's internal energy is omitted from the curriculum. Teaching in this way leads to confusion about where the energy for volcanoes and earthquakes come from and is less productive for understanding Plate Tectonics.

One of the early findings from the analysis of students' interviews was that students lacked clarity distinguishing between phenomena that are events (earthquakes and volcanic eruptions) and the phenomenological patterns these events manifest over time (faults and volcanoes). For example, some students saw volcanoes as mountains that exploded, rather than seeing the volcanic mountain as the result of multiple eruptions. While we chose volcanoes and earthquakes as phenomena that are common in Earth and Space Science curriculum, we recognize that these are really different classes of phenomena and need to be treated separately. We changed our learning progression language to earthquakes/faults and eruptions/volcanoes and an organization of the dimensions that indicate that students should move from understanding events to understanding patterns of events.

This describes the beginning of the hypothetical learning progression, which is characterized by students thinking about two of the key phenomena - volcanic eruptions and earthquakes - as releases of Earth energy, one of heat energy and the other of strain energy, introducing ideas like deformation, fracture and pressure. This also involves a shift from starting with volcanoes to focusing first on eruptions, which brings it in line with earthquakes as an event, rather than a pattern of events. It also means the levels in the learning progression can begin focusing on where the energy comes from for these events, which begins working downward into the Earth.

The next level of complexity in the learning progress then becomes patterns of events - volcanoes and faults. The complexity here comes with volcanoes and differentiating the popular (in the US) example of Hawaii, which is formed from a point source vs. the volcanoes that help build toward an understandings of plates - those volcanoes that are in chains and those that form along plate boundaries. Our approach leads to the introduction of convection and the beginning of thinking of Earth as a dynamic system rather than independent surface phenomenon.

The transition to talking about patterns of phenomenon, ultimately caused by convection, leads to the general explanation of Plate Tectonics. It seemed that mountain building, planned as one of our original phenomenon, makes more sense later in the progression. Mountains are not something that students think of as a phenomenon, but as a surface feature. To be able to think about mountains as a phenomenon with a cause and underlying process students already have to have a sense of the Earth as a dynamic system and some notions of plate movement. This means that mountain building as a phenomenon will need to develop with Plate Tectonics as an overall theory to describe all these phenomenon.

4. Contribution

While this work is preliminary, it addresses an area of Earth Science that has not been well examined in the research literature, Plate Tectonics. Earth Science is an increasingly critical area of scientific literacy as more and more socio-scientific issues are based in understandings of Earth Systems Science. A learning progression to guide curriculum, instruction, and assessment is needed as we move forward toward new science standards based on the NRC (2012) Framework. This research preliminarily identified some areas within students' conceptions of the underlying phenomena of earthquakes/faults, eruptions/volcanoes, convection and mountain building that may require a reconsideration of our approach to teaching these phenomena to middle school students in order to help them develop productive early understandings that will lead to a conceptually clear understanding of Plate Tectonics.

5. General Interest

This research will be of interest to NARST members with an interest in Earth and Space Science teaching and curriculum development. It will also interest members who are engaged in learning progressions research in other areas of science learning.

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Abstract:

This research poster describes preliminary work on a hypothetical learning progression in around the big idea of Plate Tectonics. While Plate Tectonics is a central principle in geosciences, little research has been done about students developing ideas around this concept or the underlying phenomena of earthquakes, volcanoes and mountain building. Based on open-ended, conceptual interviews (N=41) across urban, suburban and rural students in Pennsylvania, dimensions for a hypothetical learning progression are proposed. Findings suggest the possibility that emphasizing events (earthquakes and eruptions) and then moving to patterns of events (faults and volcanoes) might help students build toward a more productive understanding of earth as a dynamic system. Findings also indicated that students misattribute phenomenon that are driven by earth energy systems to processes that are driven by solar energy. These two findings taken together shape a hypothetical learning progression that focuses on short temporal events and moves toward longer term patterns of phenomena and focuses on the energy that drives those phenomena as a way to build productive early understandings as a foundation for Plate Tectonics.