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Students' Alternative Conceptions of Plate Boundaries and Their Conception Revision According to Their Reasoning Patterns

Su-Kyeong Park*

Department of Science Education, Kyungnam University, Kyungnam 631-260, Korea

Abstract: This study investigated students' alternative conceptions of plate boundaries and their conception revision according to the pattern of students' reasoning. Participants were twenty-two 10th grade high school students. All participants were asked to draw the three types of plate boundaries and to explain their drawings. Nine students participated in the reasoning activity. To this end, a semi-structured interview was conducted during which key questions were asked for the students to individually answer. The key questions used in the reasoning activity were created, by utilizing questions used in the previous studies. The findings revealed that the alternative conceptions of plate boundaries were classified into three levels based on established criteria. Students who attempted a variety of reasoning strategies such as causal reasoning, using an analogy, abductive reasoning, data reconstruction and concept combination, revised their alternative conception to a scientific conception after the reasoning activity. On the other hand, some students could not revise their alternative conceptions because they only conducted an incomplete reasoning strategy. The study also found that they were unable to use other reasoning strategies, either.

Keywords: alternative conceptions, plate tectonics, causal reasoning, using an analogy, abductive reasoning

Introduction

Plate tectonics was chosen for the domain of this study because of it's important role in understanding the hidden, explanatory mechanisms, i.e., convection, underlying continental drift, earthquakes, volcanoes, mountain formation, and sea floor spreading. The conceptual understanding in plate tectonics requires understanding the spatial arrangement of the various layers of the Earth as well as understanding the causal and dynamic movements within these layers (core as causal in heating the mantle, convection currents forming in the magma, plate movement, crust breaking/buckling etc.). In addition to acquiring these two types of knowledge (spatial/static and causal/dynamic), several concepts need to be integrated into a complex causal chain to build a rich mental model of the system (Gobert and Clement, 1999).

The existing research on students' understanding about the plate tectonics conducted to identify the different types of alternative conceptions or mental models held by students in plate tectonics. For instance, students may believe that earthquakes push tectonic plates (Barrow and Haskins, 1996; Ross and Shuell, 1993), that mountains simply grow (Trend, 2000), or that volcanic magma originates at Earth's core (Nelson et al., 1992). Some students were unsure about the location of the Earth's tectonic plates, believing them to be somewhere below the Earth's surface, with empty or dirt-filled space between the tectonic plate and the Earth's surface (Clark et al., 2011; Libarkin et al., 2005; Jeong et al., 2007). Students also draw a surprising array of models of the Earth's interior when asked to imagine cutting the Earth in half, including an Earth containing flat or no layers (Blake, 2005; Jeong and Jeong, 2007, Libarkin et al., 2005; Lillo, 1994; Smith and Bermea, 2012). Also, students holding 'the naive model' and 'the unstable model' of plate boundaries were unable to relate mantle convection and topographical features

*Corresponding author: myskpark@kyungnam.ac.kr
Tel: +82-51-290-6817
Fax: +82-51-290-6923

(Park, 2009).

Some studies reveal students' conceptions depends on their properties; Park (2011) found that the students tend to have different level concepts about the generation of magma, and the formation of the mountain ranges depending on their learning style i.e., visual learning style and verbal learning style. Also Lee et al. (2012) compares students' concepts about the plates' motions depending on the different spatial ability. The findings indicate that the students who had higher spatial ability had a better concept about the creation and extinction of plate, crustal movements, and bottom of the ocean extension, whereas the students who had lower spatial ability had misconceptions concerning these topics. Such research has received criticisms in that the student conceptions discovered in these studies do not accurately represent the concepts of students in particular situations, but rather, represent the interpretation of the researchers on students' thoughts in a general situation (Gilbert et al., 1998).

In addition to the descriptive approach for the alternative concept or mental model of plate boundaries, the prescriptive approach is needed to present teaching strategies to promote learners' scientific conception construction. In a previous study (Gobert and Clement, 1999) it was found that having students generate diagrams during their reading of a text about plate tectonics was better at promoting students' post-text conceptual understanding of the spatial, causal, and dynamic features of the domain compared to generating summaries while reading the text or simply reading the text only. Additionally, research was carried out on the integration of text and diagrams (Hegarty and Just, 1993; Vosniadou, 1994; Vosniadou, 1999). Currently, Lee (2014) emphasize the importance of teacher's role in identifying the students' interpretive process based on visual representation, and it need to improve the factors creating students' alternative conceptions about visual representation and to study the factors further.

In terms of previous research on this domain, students' alternative conceptions on plate tectonics should be applicable to a variety of learning and teaching strategies. Our goal in undertaking this study is to investigate the types and characteristics of high school students' alternative conceptions regarding plate boundaries. Furthermore, we hypothesized that students' reasoning about the causal mechanisms underlying plate tectonics would be more beneficial for revision of their alternative conceptions. Because plate tectonics is a complex concept that not only requires students to understand the basic concepts of convection, volcanoes and earthquakes, pressure and tension, but also various other concepts such as the characteristics of the mantle, continental drift, flexure and fault as well as using higher-order thinking skills. For these reasons, this research employed a reasoning activity to reveal students' conceptions revision depending on their reasoning pattern.

In this regard, a reasoning activity can serve as a good exploration method for phenomena relating to Earth Science that are difficult to verify through laboratory experiments. Induction, deduction and abduction, which are important reasoning activities in science, can be regarded as a series of elaborate system. Through reasoning, existing knowledge can interact with declarative knowledge to become new knowledge (Vosniadou et al., 2005). The characteristics of earth science phenomena make it very difficult for earth scientists collect data and understand the phenomena to be investigated. Therefore earth scientists may frequently rely on reasoning which is different from those of other disciplines of science with different contexts. Because of the large amount of time and space scale inaccessibility of earth science phenomena, earth scientists have to rely on partial, indirect evidence during research. Earth scientists could not usually isolate and control variables, hence could not conduct controlled experiment. The complexity and very complicated history of phenomena of earth and space also contribute to the role of imagination and guess work in earth science compared to other disciplines of science. These factors prevent earth scientists from using the hypothetico-deductive approach. Based on the above argument, reasoning frequently used in earth science seem to be abduction and prediction (Kim, 2002; Norman, 1983).

Abduction is the finding a best explanation for a set of observations (Peng and Reggia, 1990). It is an essential feature of many tasks, including scientific discovery (Thagard, 1989), discourse comprehension (Kintsch, 1988) In all such tasks, people explain sets of observations by generating and integrating hypotheses to form a best explanation. Such problems are often quite complex due to the number of possible elementary hypotheses for each observation and the many different ways to combine these hypotheses into an explanation. Abductive reasoning, going from the resulting state of affairs to the controlling state of affairs, must basically remain tenuous since in principle the same result can be produced by any number of premises (Peirce, 1955; Engelhardt and Zimmermann, 1982). Abductive inquiry model was suggested to be adaptable to earth science classrooms (Oh and Kim, 2005), also a reasoning-based inquiry model was proposed based on a thought experiment as a representative model without actual manipulation (Lee and Kwon, 2010). There are a number of studies that have examined students' scientific reasoning and science classroom discourses in terms of basic reasoning (Jeong et al., 2011; Lee et al., 2013; Maeng et al., 2007; Oh and Oh, 2011; Sutopo and Waldrip, 2013). For instance, Oh and Oh (2011) investigated how hypotheses were elaborated after their initial appearances in the context of scientific problem solving. Lee et al. (2013) found that the students' background knowledge were very important in the development of their reasoning. Specifically, Maeng et al. (2007) showed that more sophisticated understanding of middle school students' abductive inference during a geological field excursion. Jeong et al. (2011) revealed that the abductive reasoning of gifted children in science differed in some ways from that of scientists. Also, Sutopo and Waldrip (2013) suggested student-generated representational learning as a scientific reasoning tool for understanding and reasoning. Based on a previous study (Chen and She, 2014) the experimental group participating in scientific inquiry programs with integration of scientific reasoning generated a significantly greater number of correct hypotheses, correct evidence-based scientific explanations and a higher level of scientific reasoning than the control group.

Thus, this study aims to reveal the alternative conceptions of plate boundaries and the alternative conception revision depending on the students' reasoning patterns they use.

The study will answer the following research questions:

1. What are the types and characteristics of students' alternative conceptions regarding plate boundaries?

2. How students revise their alternative conceptions depending on their reasoning pattern?

Methodology

Participants

The participants of this study were 10th grade of high school students. 22 students were asked to draw the three types of plate boundaries described in the theory of plate tectonics, i.e., collisional, subduction and divergent boundaries. Fourweeks before the task conducted for this study, they took teacher centered classes about plate tectonics in which the teacher utilized Power Point presentations including lots of drawings and photos. The teacher was an experienced teacher (having 18 years of experience in teaching earth science for high school students). Nine students who were interested and had a willingness to engage voluntarily in the reasoning activity, participated in the activity.

Procedures

All participants of this study were asked to draw the three types of plate boundaries described in the theory of plate tectonics, i.e., collisional, subduction and divergent boundaries. The drawing assignment consisted of factors reflecting the theory of plate tectonics that are taught in the national-level science curriculum. The students were asked to draw a figure of the continental-continental boundary producing the Himalayas, the volcanic island arcs and an ocean

All participants conduct the drawing task and explain their drawings

⇓

Classify levels of all students' alternative conceptions

⇓

Nine students participate in the reasoning activity with the researcher (using key questions)

⇓

Nine students conduct the drawing task and explain their drawings

⇓

Analyze the data of the reasoning activity

⇓

Compare the students' alternative conceptions represented before and after the reasoning activity

Fig. 1. Procedure of this research.

trench (Japan and Japan trench), and the sea-floor spreading along the mid-ocean ridges. Also they were asked to indicate the mantle convection and plate movement with arrows and explain the changes in the lithospheric plates. The written portion allows students to explain the drawings in their own words, and clarifies their conceptions for the raters. These written responses also allow the raters to validate meanings constructed from students' drawings. Students were asked to explain their drawings after the task. One camcoder was used which recorded the student's drawings and voice as they explained in real time. The levels of students' alternative conceptions regarding the plate boundaries were revealed by analyzing the drawings and voice data based on the analysis criteria. The three raters referred to the alternative conception categories presented in the previous study (Park, 2009) to set the criteria for the plate boundaries. The analysis criteria for three levels of alternative conceptions regarding plate boundaries are shown in Table 1. We individually classified the level of students' alternative conceptions and engaged in a discussion to compare and allign with the analysis.

Data Analysis

The researcher and two Earth Science teachers analyzed the data from students' drawings and the discourse of reasoning. Of the raters, one was in the process of obtaining her Ph.D. degree in Science Education, and the other was in the process of obtaining a Master's degree. We categorized the level of alternative conception a whether the students could distinguish the plate from the mantle, demonstrates topographical features of plate boundaries and also relate mantle convection and topographical features of the three boundaries.

Nine students participated in the reasoning activity; a semi-structured interview during which the students were individually asked similar questions and responded to these questions. The key questions used in the reasoning activity were created, referring to questions used in the previous studies (Gobert, 2000; Gobert and Clement, 1999) (Table 2). In particular, questions that may give information to the students are asked by

Table 1. Criteria for the three levels of students' alternative conceptions regarding plate boundaries

Type	Criteria
level 1	Does not distinguish the lithospheric plates from the mantle. Does not explain the motion of the lithospheric plates. Does not demonstrate the features of the plate boundaries
level 2	Distinguishes the lithospheric plates from the mantle inappropriately. Explains the motion of the lithospheric plates and mantle incompletely. Demonstrates the features of the plate boundaries incompletely. Does not relate the mantle convection or the plate motion and the features of the three boundaries.
level 3	Distinguishes the lithospheric plates from the mantle. Explains the motion of the lithospheric plates and mantle incompletely. Demonstrates the features of the plate boundaries incompletely. Relates the mantle convection or the plate motion and the features of the three boundaries.

Table 2. Key questions used in the reasoning activity

Type	Questions
Collisional boundary	Where does the force to move the two plates arise from? Why is the Himalaya Range so tall? What are the associations between fossils found in the Himalayas and its height?
Subduction boundary	How would the ocean trenches look if we were to go to the bottom of the sea in a submarine? If we were to travel in the ocean trenches, what kind of landscape would we see? What is the phenomenon that occurs in the Pacific Ocean due to many ocean trenches? Can you explain how the volcanic island arcs form?
Divergent boundary	What happens on the oceanic ridge? When the mantle pushes and lifts, what would be the shape of the oceanic ridge? How would the oceanic ridge look if we were to go to the bottom of the sea in a submarine? What happens at the peak of the mountains? Why are magma eruptions severe especially at the bottom of the sea?

Table 3. Students' reasoning strategies used in the reasoning activity

Reasoning strategy	Definition
Causal reasoning	Strategy to identify causalities, and relationships between a cause and effect.
Using an analogy	Using an analogy is a strategy to point out relevant parallels that could utilize experience and an example as a guide. Image-based analogy is centered on the objects, pictures or photos while case-based analogy is generated from direct or indirect experience.
Abductive reasoning	The type of reasoning whereby one seeks to explain relevant evidence by beginning with some commonly well known facts that are already accepted and then working towards an explanation.
Data reconstruction	Strategies to screen for evidence by giving students a problem to solve or re-arrange the information considered necessary so that the number of inference rules to make it easier.
Concept combination	To form a new concept by combining two or more. Using this strategy to infer new concepts and rules.

the teacher in the reasoning activity may affect the thinking process of the students. In order to reduce these limitations, we conducted the reasoning activity, centering on the key questions that were created during a prior meeting. A camcoder recorded the entire dialogue between the student and the researcher during the reasoning activity and three raters analyzed transcripts.

The researcher conducted the reasoning activity with key questions that were created during a prior meeting by three raters. Raters analyzed the students' reasoning pattern through the entire discourse between student and researcher during the reasoning activity. In order to increase reliability, raters shared and discussed about the reasoning strategies before analyzing the script. First, we individually analyzed the entire transcript of the reasoning activity. There was disagreement related to the segment length and similarity in reasoning strategies; this disagreement was clarified through discussion. Repetitive analysis allowed the final coding to be completed with consistency.

The reasoning strategies used by the students were found as Table 3 and defined referring to the definition used in the previous research on this domain (Oh, 2006; Johnson and Krems, 2001; Magnani, 2001; Thagard, 1989).

Results and Discussion

Different Levels of Alternative Conceptions regarding Plate Boundaries

Fig. 2 displays example drawings of each alternative conception regarding three boundaries. The student shows level 1 conception (C-1) regarding collisional boundary do not differentiate the lithospheric plates from the mantle and do not explain the motion of the lithospheric plates. It includes an alternative concept

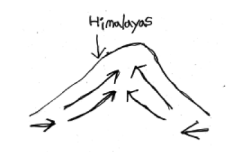
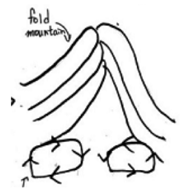
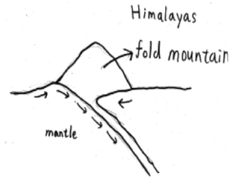
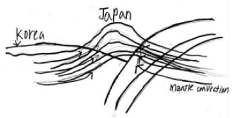
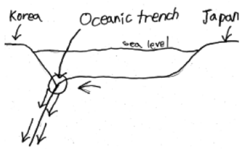
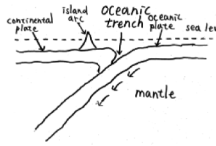
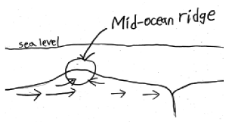
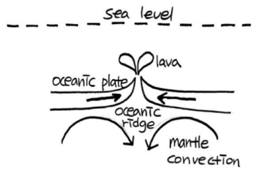
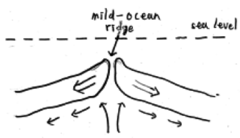
<table>
<tr><th></th><th>level 1</th><th>level 2</th><th>level3</th></tr>
<tr><td>collisional boundary</td><td></td><td></td><td></td></tr>
<tr><td></td><td>C-1</td><td>C-2</td><td>C-3</td></tr>
<tr><td>subduction boundary</td><td></td><td></td><td></td></tr>
<tr><td></td><td>S-1</td><td>S-2</td><td>S-3</td></tr>
<tr><td>divergent boundary</td><td></td><td></td><td></td></tr>
<tr><td></td><td>D-1</td><td>D-2</td><td>D-3</td></tr>
</table>

Fig. 2. Students' drawings representing the three plate boundaries.

of the topographical features namely the base of the plate as being flat, with only the surface of the plate lifted. In comparison, the student that has level 2 alternative conception (C-2) incompletely differentiate the plates from the mantle and explain the motion of the plates and lower mantle. He did not associate mantle convection and cause of topographic features.

The level 3 alternative conception shown in C-3 represents an unclear distinction between the mantle and the plate. However, it clearly depicts the direction of movement and subduction of the Indian Plate and the Eurasian Plate. Also, it shows that the subduction of the plates while the sedimentary layer in between is pushed upward to form the mountain range. During the interview, the student who has C-3 conception gave an explanation by associating the movement of the mantle and the plates with the topographic formation. However, he demonstrated no association between the height of the mountain range and the sediment under the sea. Such conception results from the lack of in-depth understanding of the dynamic process of the thick sedimentary layer of submarine strata rising due to plate collision.

The learner who has level 1 conception (S-1) could not distinguish the plates and the asthenosphere of mantle and had an alternative concept in the motion of the lithospheric plates. During the interview, she could not give a basic explanation of the forms of the volcanic island arcs and ocean trenches. The learner who has level 2 alternative conception (S-2) drew an oceanic trench and Japanese island. However she misunderstood the location of the oceanic trench and the process of the volcanic arc formed by oceanic-continental subduction. During the interview, this learner showed static conceptions of the morphological features or the formation mechanisms of the volcanic island arcs and was thus classified as an unstable model. S-3 shows that the ocean trenches form as the oceanic plate (Pacific plate) sinks underneath the continental plate (Eurasian plate). It depicts the location of the ocean trenches with direction of the mantle, however it did not represent topographic

Table 4. The students' revision of alternative conceptions before and after the reasoning

	collisional boundary		subduction boundary		divergent boundary	
	before	after	before	after	before	after
S1	level 2	level 3	level 2	level 2	level 2	level 2
S2	level 2	level 2	level 2	level 3	level 1	level 2
S3	level 2	scientific concept	level 2	level 3	level 2	scientific concept
S4	level 2	scientific concept	level 3	level 3	level 3	level 3
S5	level 2	level 2	level 2	level 2	level 1	level 1
S6	level 3	scientific concept	level 2	level 3	level 2	scientific concept
S7	level 2	scientific concept	level 2	level 2	level 2	scientific concept
S8	level 2	level 2	level 1	level 1	level 1	level 1
S9	level 3	level 3	level 2	level 3	level 1	level 2

features and the overall directionality of the plate movement in detail. Although he did not represent the formation of magma in the drawing. Because he gave a more appropriate explanation during the interview, he was classified as having a causal model in the final analysis.

With respect to the alternative conception regarding the divergent boundary depicted in D-1, shows the motion of the lithospheric plates and mantle incorrectly. During the interview, he demonstrated that the oceanic crust is formed as the mantle itself moved and lifted, and thus was classified as level 1. Concerning D-2, the motion of the lithospheric plates and the lower mantle are incompletely represented. This learner misunderstood the direction of mantle convection in which mantle currents are similar to those of the collisional boundary. She incompletely demonstrates the topographical features of the plate boundaries namely, mid-ocean ridge similarly look like a fold mountain. D-3 shows correct direction of convection in the asthenosphere of mantle and the movement of the lithosphere. During the interview, it was confirmed that he did not recognize that the mountaineous terrains are formed as magma rises. In particular, there was the biggest dispute among the raters while analyzing the alternative conception of this student before finally classifying him as a causal model.

Case study; revision of alternative conceptions after the reasoning activity

The students' alternative conceptions are partly revised to a higher level after a reasoning activity, on the other hand a few students' alternative conception was not revised after the reasoning activity. Nine students' conceptions revision who participated in the reasoning activity are described in Table 4. In the next section four cases studies are described; S3 and S6 students revised all three plate boundaries, S2 revised two plate boundaries and S8 did not revise at all. S8 was chosen because his dialogue was more diverse than S5 even though both of them did not revise in three alternative conceptions. The underlined discourse of the dialogue below shows the reasoning process, especially the students' reasoning strategies are placed in italics.

Student 3's reasoning pattern and revision of alternative conception

Student 3(S3)' drawing of fold mountains shown in Fig. 3a shows no association between the height of the mountain range and the sediment under the sea. He shows level 2 alternative conception regarding the collisional boundary before the reasoning activity.

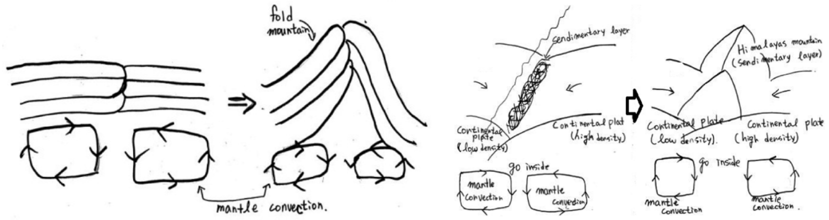
R: The Himalayas are the world's tallest mountains, towering more than five miles above sea level. Why is the Himalaya Range so tall?

S3: *I thought that both 2 plates were pushed upward instead of one plate going down and the other up, because the density of two continental plates is similar.*[causal reasoning]

R: Were those lifted upward like a tower?

S3: Yes, when the plates collided they pushed one another upward.(*Alternative concept*)

R: Where does the force come from to move the two



(a) Before the reasoning (b) After the reasoning

Fig. 3. Student 3' drawings regarding collisional boundary created before and after the reasoning activity.

plates?

S3: *It comes from the mantle below the plates.*[causal reasoning]

R: What changes occur due to the force?

S3: *Because they push each other... The plates that were apart and are then forced into a collision……* [concept combination]

R: Can the mountain become thick and tall just because of plate collision?

S3: Is there something above the plates?

R: What kinds of fossil are discovered in the Himalayas?

S3: *Clamshells are found in strata of the Himalayas...*

R: How did they get there?

S3: *Because the earth under the sea was lifted upward.*

R: Now from that, can you explain why the mountain range is so tall?

S3: A-ha... *The earth underneath the sea was pushed and lifted upward.* [abductive reasoning]

R: When the fast moving Indo-Australian plate had completely closed the Tethys Ocean, there were thick sedimentary rocks settled on the ocean floor. Since these sediments were light, they crumpled into mountain ranges rather than sinking to the floor.

R: Let's talk about the earthquake and volcano in this area. Have you heard of China's 2008 Sichuan earthquake?

S3: Yes I have.

R: Can you explain why the earthquake occurred in this area associated with tectonic plate movement?

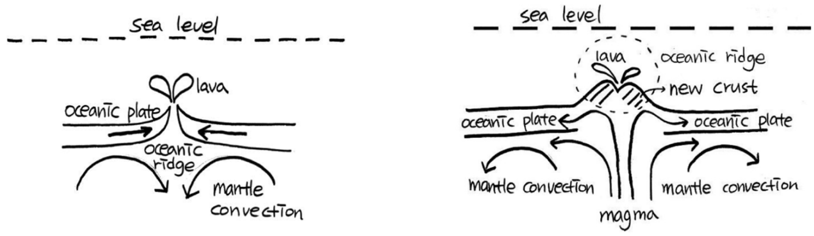
S3: *The earthquake took place in this area as a result of the collision between two tectonic plates, the Indian plate and the Eurasian plate. This created a lot of tension, and a lot of earthquakes.*[data reconstruction]

Student 3 could not infer first that the height of the gigantic fold mountains is associated with the submarine sediment, and instead explained it only as being caused by plate collision. Such a low level conception results from the lack of in-depth understanding of the dynamic process of the thick sedimentary layer of submarine strata rising due to plate collision. However, utilizing well known facts such as the fossils of submarine organisms that were found in the Himalayas, student 3 inferred that the submarine strata was lifted above sea level. This is an example of abductive reasoning which is to explain cause/effect relationships by applying existing facts and rules. Furthermore he showed a variety of reasoning strategies such as causal reasoning, concept combination and data reconstruction to describe the geological phenomena due to the movement of the plate.

Fig. 3b shows his drawing after the reasoning activity, it represents that student 3 recognized the causal relationship between the thickness of the fold mountains and the seabed sediment. His alternative conception revised to a scientific conception after the reasoning activity.

Student 6's reasoning pattern and revision of alternative conception

The focus is on the drawing of an oceanic ridge by student 6 (S6) shown in Fig. 4. Because student 6 could not explain the structure of ocean ridges in relation to the concept of rift valleys or mantle convection, she was classified as having level 2



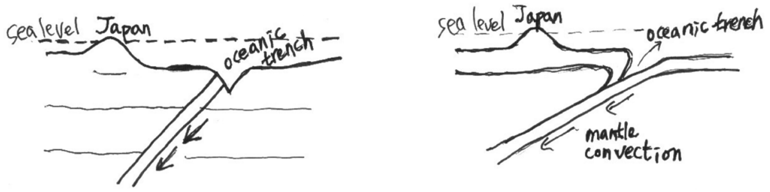
(a) Before the reasoning (b) After the reasoning

Fig. 4. Student 6' drawings regarding divergent boundary created before and after the reasoning activity.

alternative conception before the reasoning discussion. She believed that mantle goes down below the plate in the oceanic ridge likely fold mountains. Before reasoning activity, Student 6 also could not give a valid explanation regarding the topographic features of an oceanic ridge. The following is an excerpt, taken from the discussion between student 6 and a researcher.

R: How would an oceanic ridge look if we were to go to the bottom of the sea in a submarine?
S6: We would see a mountain range on the bottom of the sea.
R: Can you predict the direction of mantle movement under the submarine mountain range?
S6: The plates would collide with each other to make a mountain range. As a result, the mantle goes down below the plate. (*alternative conception*)
R: What is happening at the top of the mountain range?
S6: Magma is coming upward. (*exposed to the contradictory situation*)
R: Also, the oceanic ridge is divergent. What do you think is the meaning of 'divergent'?
S6: I think it means spreading out. Crusts move far away from each other..
R: What should the direction of the mantle be for magma to come up and the crust to spread out.
S6: *The mantle should push upward.*
R: Can you describe the convection currents of the mantle and the shape of the oceanic ridge?
S6: *I believe that the pressure of the mantle pushes the crust up to construct a mountain range at the bottom of the sea.*.[data reconstruction]
R: What's the terrain like at the top of the oceanic ridge?
S6: *It looks like a water fountain because the peaks of the oceanic ridge are formed like a rift valley, as the divaricated water is shot up into the air.* [using an analogy]
R: The magma on the oceanic ridge forms due to reduced pressure after it is pushed outward because of mantle convection.
R: When continents on the earth's surface formed the Pangaea, is it located in the Atlantic?
S6: No, I don't think so.
R: Can you explain the process in which the Atlantic was created?
S6: *As both continents moved away from each other, it created a narrow sea. Over time the sea became increasingly wider and wider because of the oceanic ridge.* [data reconstruction]
R: Today, there is a continental split. Have you heard about it?
S6: I've heard there is a great rift valley in East Africa. It appears to be developing a divergent tectonic plate boundary.
R: What will happen in the future of the world's geological surface?
S6: *The geological surface will be completely different from it's present state* [concept combination]

Student 6 was asked to picture an oceanic ridge and explain the direction of movement of the mantle. Her response was that the mantle goes down below the plate which was identified as a misconception. This student was exposed to a contradictory situation by being asked about the mountains summit. Due to the exposure to a contradictory situation, student 6 combined the concept and it's abductive reasoning. In addition, when she was required to relate the convection currents of mantle and the shape of the oceanic ridge,



(a) Before the reasoning (b) After the reasoning

Fig. 5. Student 2' drawings regarding subduction boundary created before and after the reasoning activity.

she used the analogy of a water fountain. This image-based analogy provided an opportunity to visualize the oceanic ridge. Finally student 6 attempted to re-arrange the information by demonstrating the process in which the Atlantic was generated.

Student 6 was asked to draw three plate boundaries after the reasoning activity, drawings on the divergent boundary created before and after the reasoning activity is shown in Fig. 4. We discovered that an alternative conception of student 6 revised to a scientific conception.

Student 2's reasoning pattern and revision of alternative conception

Student 2 (S2), who was shown to have a level 2 conception regarding the subduction zone before the reasoning activity, provided reasoning and explanation of the ocean trenches and volcanic island arcs as follows:

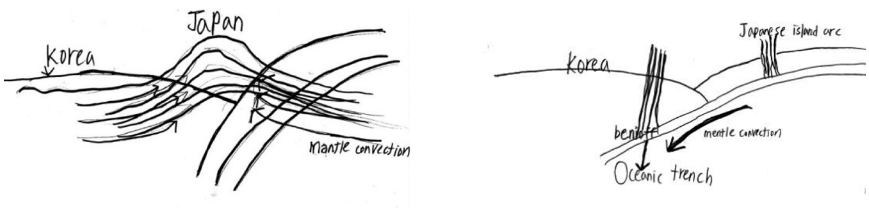
R: How would the ocean trenches look if we were to go to the bottom of the sea in a submarine?
S2: *........ The terrain is off recessed like a pool.* [using an analogy]
R: Do you mean that it looks like a well?
S2: *Not a well. Rather, a long valley.*[using an analogy]
R: What is the phenomenon that occurs in the Pacific Ocean due to the many ocean trenches?
S2: There are many earthquakes and volcanic activities.
R: Can you explain how the volcanic island arcs form?
S2: *This is... the plate... The density of the marine plate is high.*[causal reasoning]
R: How can magma be lifted up?
S2: Magma... is light.
R: What is the topography of the seabed outside Japan
S2: Japan trench?
R: What is the cause Japan Trench was created?
S2: *Because of mantle convection...*[causal reasoning]
R: Can you explain how the volcanic island arcs, Japan form?
S2: *Because the magma coming up.* [incomplete reasoning]
R: Why the magma coming up through the crust ?
S2: ------------
R: Magma comes up through the weak spots of the crust.

Unlike students with a level 2 conception, student 2 gave adequate reasoning for the appearance of ocean trenches observed from a submarine. He used the analogy of a pool first, he revised it to a correct analogy; a long valley. However, when student 2 was required to demonstrate how Japan island form, he did not seem confident about the mechanism of the volcanic island arcs formation. Fig. 5b shows his drawing after the reasoning activity, it represents that student 2 can not recognize the causal relationship between the features of the volcanic island arcs and the motion of the magma. His level 2 conception regarding the subduction zone revised to a level 3 conception after the reasoning activity

Case without revision in alternative conception

The following extract, taken from the discussion of student 8 (S8) and a researcher in the reasoning activity of the oceanic trench and volcanic island arcs. The focus is on the drawing of an oceanic trench by student 8 shown in Fig. 6.

R: How would an oceanic ridge look if we were to go to the bottom of the sea in a submarine?
S8: There might be something similar to volcanoes. [alternative conception]



(a) Before the reasoning (b) After the reasoning

Fig. 6. Student 8' drawings regarding subduction boundary created before and after the reasoning activity

R: Do you mean that magma erupts near oceanic trenches?

S8: I'm not sure……

R: What kind of terrain is generated when one plate is dragged underneath another plate.

S8: *The plates collide into each other and are lifted up* [incomplete reasoning]

R: Are they really lifted? Isn't a valley generated because the plates slide downwards.

S8: …………

R: What created the Trench of Japan?

S4: *It is because both plates collided with each other* [incomplete reasoning]

R: What is the phenomena that occurs in the area surrounding the Pacific Ocean?

S8: That's easy! *The Pacific plate crashed with the Eurasian plate* [incomplete reasoning]

R: Well, how were the Japanese volcanic island arcs formed? Can you explain how the volcanic island arcs were formed by using this picture?

S8: The denser Pacific plate sunk underneath the less dense Eurasian plate.

R: An oceanic plate can subduct underneath a continental plate because of the density of marine plate is higher than that of the continental plate. It depends on the components of plates.

Student 8 showed inappropriate reasoning regarding an oceanic trench where the plates collide with each other and are lifted up. He focused on plate collision instead of plate subduction regarding the mechanism of oceanic trench creation. He knew the differences in plate density, but could not explain what happens in terms of the movement of plates because of the difference in density. He could not revise his alternative conceptions because he only conducted incomplete reasoning, also he could not use other reasoning strategies.

Conclusion and Implications

The purpose of this study are to investigate students' alternative conceptions of plate boundaries, and their conceptions change depending on the pattern of reasoning that they use. In the previous studies, there was a common tendency for students with the 'static unstable model' to describe the plate movement using vague words, while those with the 'dynamic model' presented a dynamic point of view of the Earth's crust and mantle (Gobert, 2005; Libarkin et al., 2005; Samarapungavan et al., 1996; Sibley, 2005). Within the context of the preceding discussion, the present study analyzed alternative conceptions of plate boundaries of high school students. In order to reveal the alternative conceptions of students, we made an attempt to analyze their drawings and explanatory discourse about it.

The results of this study, regarding alternative concepts by high school students appear as follows. A representative example of an alternative concept regarding fold mountains is that continental plate itself formed the high mountains without the sediment that was in between the two plates. This type of alternative concept is similar to that of students who thought plates existed in the form of flat plates as in a previous study (Libarkin et al., 2005). On the contrary, the volcano and earthquake are not represented in detail in oceanic ridge furthermore alternative concept was exposed in the form of towering peaks without rift valley. The reason for this trend was interpreted as a lack of focus in Korean Science textbooks on the differences between illustrations of volcanic island arcs and oceanic ridges. For instance, the illustrations of volcanic arcs included volcanic eruption, however, the figure of oceanic ridges did not include volcanic eruptions. The finding in this study should be considered as a starting point for the redesign of textbooks and considered when constructing a new curriculum. Hopefully the findings in this study may shed some light on redesigning the instructional strategies for conceptual change and provides empirical data for further in-depth investigation of students' thinking processes.

Teaching strategies such as focusing on verbal interaction between teacher-student are required to enhance the alternative conceptions. Besides the characteristics of earth science phenomena, such as time-scale, space-scale, accessibility, complexity, and controllability mean that earth scientists have no access to them, and thus they only rely on partial, indirect evidence. Hence the causal inquiry also requires abductive reasoning to learn the plate tectonics theory. Therefore we assume that the reasoning process would be more beneficial for revision of their alternative conceptions. Students should be encouraged to infer the underlying mechanisms in plate tectonics through reasoning activities. Thus, this study aims to reveal the alternative conception revision depending on the students' reasoning pattern. In a previous study, elementary school children were often able to describe specific events that might result in modern features from rock formation to the Earth's interior, and demonstrated the ability to use a variety of knowledge types in the context of their retrodictive reasoning (Libarkin and Matthew, 2012). Furthermore we discovered that high school students who attempted a variety of reasoning strategies such as causal reasoning, abductive reasoning, concept combination and data reconstruction, changed their alternative conception to a scientific conception after a reasoning activity. Meanwhile, some students attempted the limited reasoning strategies partly revised their alternative conception. Other students revealed an unchanged alternative conception after the reasoning session. They could not combine a physical property such as density and observed phenomena. This means that they only conducted an incomplete reasoning strategy, they were also unable to use other reasoning strategies.

Therefore, if the learner does not take advantage of reasoning strategies, the teacher should be more involved to strengthen their reasoning activities. We then suggest ways in which practical reasoning may be developed in students so that they are enabled to better understand how scientific knowledge is produced and how they may be better able to contribute to improving scientific practices. Perhaps the value of this research is that it has offered concrete suggestions for the ways that can change the alternative conceptions. This work provides a basis from which curricula for teaching earth science can emerge, and suggests that new studies into the reasoning abilities of learners are needed, including curricula that encourage inference of the past from modern observations. Research is needed to reveal the relationship between the learner's epistemological beliefs and their alternative conception, to find out how other cognitive factors such as metacognition and creativity could affect alternative conceptions.

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