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A Comparative Analysis of Earth Science Curriculum Using Inquiry Methodology between Korean and the U.S. Textbooks

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The purpose of this study is to investigate in what ways the inquiry task of teaching and learning in earth science textbooks reflect the unique characteristics of earth science inquiry methodology, and how it provides students with opportunities to develop their scientific reasoning skills. This study analyzes a number of inquiry activities in both Korean and American earth science curriculums by using an analysis framework of earth science inquiry methodology. Results suggest that Earth science activities in Korean textbooks appropriately reflect comprehensive earth science methodologies and provide students with more opportunities to develop their earth scientific literacy, while the American curriculum used in the U.S. included only a small number of inquiry-based activities.

Keywords: Scientific Literacy, , Scientific Reasoning, Inquiry Methodology, Earth Science Curriculum

INTRODUCTION

Scientific literacy has long been a major goal in school science teaching and learning in K-12 education and in the development of its curriculum (National Research Council (NRC), 1996). Studying Earth science is one way to help achieve scientific literacy since a predominant goal is for students to fully understand the Nature of Science (NOS) and develop their skills and abilities within scientific inquiry and reasoning (American Association for the Advancement of Science (AAAS), 1990). Earth science students develop their scientific reasoning skills through inquiry-based activities that should provide them with context and situations related to Earth systems. Particularly to develop the ability of scientific reasoning in earth science inquiry activities, students need to understand the earth scientific method including principles, processes, and logical skills that earth science researchers use in their studies (Kim, 2002). Earth scientific reasoning is different from other sciences' methodologies, and relationally could be utilized to solve problems in everyday life. In addition, scientific reasoning would be a useful tool to resolve problems and issues pertaining to our Earth's environment. Therefore, scientific reasoning skills should be an ability required for the scientifically literate citizen (Frodeman, 1995) since students' understanding of inquiry methodology in studying earth science would be an important way to raise their overall scientific literacy. Moreover, students are able to develop an insight into the earth environment via a system approach toward the earth investigation, which is one earth science inquiry methodology (Orion & Ault, 2007).

Earth science education, however, has been a low priority in implementing school science curriculum since the 7th curriculum reform in Korea. In addition, only 10% of U.S. high schools offer earth science courses (Park, 2005). Earth science has been considered as a secondary science because it relies on skills used in physics (Frodeman. 1995). This status of earth science education is, in part, attributed to inappropriate earth science instructional resources including lack of inquiry

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activities for earth science, and oversight of idiosyncratic characteristics of earth science (Exline, 1998). The change toward inquiry-based methodologies on a large scale would not be possible without the development of appropriate materials (Anderson, 2007). Specifically, science textbooks should connect curriculum to science teaching and learning (Kim, et al., 1994), and inquiry activities in the textbook should have more influential materials (Kulm, et al., 1999). Therefore, earth science education needs to move forward with an inquiry process model in which inquiry tasks in science textbooks should be constructed in a way that reflects the attribute of earth science (Oh, 2005) and delivers it using inquiry methodologies.

The purpose of this study is to investigate in what ways the inquiry task in earth science textbooks reflect the unique characteristics of earth science inquiry methodology, and how it provides students with opportunities to develop their scientific reasoning skills in earth science. In particular, it provides an important niche to compare the earth science curriculum between Korea and the United States, and to establish a scope and sequence that is desirable to any of the extant earth science curricula. This study analyzes a number of inquiry activities in the extant earth science curricula by using an analysis framework of earth science inquiry methodology. The following sections will discuss how inquiry activities from earth science textbooks between two countries are portrayed in terms of the unique characteristics of earth science inquiry methodology.

THEORETICAL FRAMEWORK

Each science discipline has its own dimension to study. In fact, science disciplines differ from one another in terms of realm of study and techniques used in that process (AAAS, 1993). The scientific method of inquiry is particularly context specific. The project 2061 specifically stressed this point suggesting, "Scientific inquiry is not easily described apart from the context of particular investigations. There simply is no fixed set of steps that scientists always follow, no one path that leads them unerringly to scientific knowledge" (AAAS, 1990, p. 4). There are, however, certain features of scientific inquiry in earth science. Learning earth science provides a unique possibility of seeing time and place. Many subjects in earth science help us understand that the earth is a dynamic sphere and an interactive system composed of a stabilized cycle. The system operates in various scales of both time and place. Some systems are too big to even imagine its limit or borders. Orion and Ault (2007) succinctly depict the characteristics of investigating and understanding earth science:

Investigating the earth depends heavily upon spatial reasoning and visual representation… Understanding how the earth works requires retrospection and retrodiction, making inferences about the past. …by interpreting the present as the outcome of natural experiments on vast scales and sleuthing out its causal history, earth science set the stage for making extrapolation about possible future (p. 654-657).

Thus, according to Orion and Ault (2007) a distinctive feature of inquiry in earth science can be a historical approach, that is, the concern for complex systems: hydro, geo, atmos, interaction with the biosphere, the conceptualization of very large-scale phenomena through time and across space, the need for visual representation, the integration across scales of solutions to problems, and the uniqueness of retrospective scientific thinking. These characteristics of earth science provide a unique niche for the development of the earth science curriculum. For instance, earth science textbooks should be structured around a series of scientific inquiry tasks that pertain to the aforementioned unique characteristics. The implementation of this type of curriculum in schools would subsequently help students to inherently understand the features of scientific inquiry method in earth science.

In this study, the inquiry analysis framework developed on the base of the features of earth science inquiry methodology (Kim, et al., 2005) was used to examine distinctive earth science inquiry methodologies reflected in the science textbooks. The framework divided earth science methodology in three ways: *logical inference method, hermeneutic method,* and *historical method* (Appendix A). The logical inference method is subdivided into *inductive method, deductive method, and abductive method* (Engelhardt & Zimmermann, 1982; Kim, 2002; Magnani, 2001). The hermeneutic method consists of *circular reasoning; forestructures of understanding;* and *historical nature of human understanding.* The historical method includes the strategy and procedure used by earth scientists when exploring the history of earth: *adhering to the modern principle of uniformitarianism; place substituting for time in stage theorizing; relic interpretation; constructing proper taxonomies;* and *evaluating independent lines of inquiry for convergence* (Ault, 1998; Kim, et al., 2005). In this study, researchers particularly utilized the framework of hermeneutic and historical methods to analyze all domains of earth science because geology is similar to the other domains of earth science such as astronomy, oceanology, meteorology in terms of the quality of inquiry subject and method (Kim, 1995). In addition, the historical nature of human understanding in the hermeneutic method could be applied to other areas of sciences (Frodeman, 1995). Previous research (E.g., Gould, 1986) also suggests that the historical method is an appropriate response to the demand of extrapolation from observable events across time and place into unobservable scale. Therefore, this is an appropriate method to reason directly unobservable events from observable events in other domains restricted by time and place.

METHOD

The study used two textbooks for analysis including *Holt Science & Technology Earth Science* (Kathleen, et al., 2005), and *High School Earth Science I and II* (Kyung, et al., 2003). Though there are several Earth Science textbooks, each were chosen because they are the textbooks most oft used in the U.S., and Korea, respectively. As cited in the literature, Korea has a National standard curriculum for Earth Science in high school whereas a variety of Earth Science curricula are available throughout the U.S. and are modified dependent on local and state requirements (Park, 2005). As students study with these curriculums, international standardized science tests have shown that Korean students consistently outscore students in other countries, including the U.S. (Martin, et al., 2000). Both curriculums, however, have one thing in common: Both were published after the reform with the National Science Education Standard in which 'inquiry' was emphasized in the reform outcome.

The two aforementioned curriculums were selected to compare the characteristics of inquiry tasks that were particularly designed to use earth science inquiry methodology. With an inquiry analysis framework based on the features of earth science inquiry methodology, the entire inquiry activities included in both textbooks were analyzed. In the format comparison between the two curriculums, a majority of the inquiry tasks in the Korean textbook consisted of three components: Preparation, Conducting Experiments, and Conclusion; whereas inquiry activities in the U.S. text consisted of Objectives, Materials, Safety, Asking a Question, Forming a Hypothesis, Testing the Hypothesis, Analyzing the Results, and Drawing Conclusions. For the purpose of analysis, the logistical information including Objective, Materials, and Safety was excluded. Instead, researchers analyzed the questions and sentences that asked students to perform tasks.

First, researchers coded each of the inquiry tasks by the unit of sentence (i.e., one complete sentence including a question) into three methods: logical method, hermeneutic method, and historical method, which were used as a framework of Earth science inquiry methodology. Researchers then calculated a relative frequency of each method to the total number of features. Next, the Earth science inquiry methodology was categorized into six domains of Earth science: Geology, Astronomy, Meteorology, Oceanology, Environment, and Inquiry method. Relative Frequency of each method was calculated in each of the domains. Researchers also used the domain of 'Environment' for the inquiry tasks that included the subject about global climate change, global scale of cycle, and environment-related activities. Third, a calculation of a percentage of each feature to the total number of inquiries was conducted in order to find out what percentage of each of the earth science methodology features in each domain was used (see Table 4). To ensure reliable data collection, the process of analysis per each of the tasks used two experts in science education (one university professor and the other with PhD in Earth science education) until reaching at least 90% agreement about the use of inquiry analysis framework. Instances where the raters faced less than 90% agreement, the items were discussed and re-rated until reaching 90%. The average final agreement rate of analysis results in inquiry activities was 91.9% between the two raters.

RESULTS

Foremost, researchers compared the entire distribution of domains in each earth science textbook to find the overall difference of inquiry tasks in earth science curriculums between the U.S. and Korea. Results showed that Korean earth science curriculum has the distributions of geology (31.88%), astronomy (28.99%), meteorology (16.67%), oceanology (11.59%), environment (7.25%) and inquiry method (3.62%), and the U.S. curriculum has the distribution of geology (36%), astronomy (24%), meteorology (16%), oceanology (6%), environment (10%), and inquiry method (8%). The patterns of the U.S. earth science curriculum were apparently similar to that of Korean curriculum except for oceanology, which was almost twice lower. In addition, geology took the largest portion in the U.S. curriculum, and twice more inquiry method activities over the Korean curriculum.

Regarding the types of inquiry, the Korean curriculum included four different types of inquiry tasks: exploring activity (36.99%), interpreting data (35.62%), discussion (5.48%), and experiment (21.72%); whereas the U.S. textbook included inquiry tasks; experiment (9.10%), using models (45.45%), making models (36.36%), and interpreting data (9.09%). Unlike the Korean curriculum, the U.S. curriculum hardly used activities on exploring, interpreting data, and discussion activity. Instead, using models was the activity for students to explain natural phenomena with the model that they made by applying earth scientific principles or the principle of observational equipments to the activity.

When we consider the activity of experiment, using models, and making models as hands-on laboratory investigations in which students perform with actual materials, the U.S. curriculum included more hands-on laboratory investigations than the Korean curriculum. In particular, inquiry activities in the U.S. curriculum

Table 1. The Relative Frequency of Earth Scientific Methodology in Korean and U.S. Curriculums

Methodology	Korean textbook		U.S. textbook	
	Relative frequency	Number	Relative frequency	Number
Inductive method	43.49%	177	34%	85
Abductive method	30.96%	126	39.6%	99
Deductive method	12.78%	52	19.2%	48
Not using any logical method	12.78%	52	7.2%	18
Total	100%	407	100%	250
Circular reasoning	15.28%	79	13.31%	39
Forestructures of understanding	74.47%	385	79.52%	233
Historical nature of human understanding	6.96%	36	2.39%	7
Not using any hermeneutic method	3.29%	17	4.78%	14
Total	100%	517	100%	293
Adhering to the modern principle of uniformitarianism	12.56%	54	18.25%	50
Place substituting for time in stage theorizing	1.16%	5	0.73%	2
Relic interpretation	4.19%	18	5.84%	16
Constructing proper taxonomies	29.53%	127	15.33%	42
Evaluating independent lines of inquiry for convergence	0.93%	4	0%	0
Not using any historical method	51.63%	222	59.85%	164
Total	100%	430	100%	274

Note. Number is the number of methods coded

involved more hands-on investigations that required students to apply the content knowledge rather than just confirm the concept, which was characteristic of the Korean curriculum. For instance, in an activity "Creating a Calendar on the Mars" in the U.S. textbook, students were asked to make a calendar of each planet's cycles of rotation and revolution by using the concept of the Earth's rotation and revolution around the Sun. The curriculum then suggested that students' role-play in making the earth movement around the constellations of the zodiac. Presumably, each of the students would become a different constellation by standing in relative proximity to each other. In this way, participating students would notice a change of constellations while they themselves were moving and in effect, learn that the Sun's yearly travel could not be evidence of the Earth's revolution around the Sun.

Earth Science Inquiry Methodology Presented in Both Curriculums

Logical Inference Methodology

Table 1 shows a relative frequency of features of earth scientific methodology in inquiry activities demonstrated in both curriculums. The differences between the two curriculums were statistically significant (t=3.21, p<0.025, 2-tailed), and the number of activities in each methodology in two curriculums was highly correlated (r=0.96, p<0.000). In Korean earth science curriculum, the inductive method was dominantly used followed by the abductive method and the deductive method. One of the reasons for this pattern is that there are many activities to discover tendency or compare and classify and find out a generalized principle through interpreting data or exploring activity. Unlike the pattern of Korean curriculum, the U.S. textbook used more abductive method than the inductive method in inquiry activities. One of the reasons is that most of the activities started with "Ask a Question" and included the steps in which students posed a question and a hypothesis. In this process, students used abductive reasoning that would explain a cause of phenomena or a new idea. Interestingly, this study found that both curriculums did not use much of the deductive method. One of the reasons is that the U.S. curriculum used inquiry activities that required to observe or to explain the earth scientific phenomena by using models that the students were required to make firsthand. Therefore, the deductive reasoning was rarely used in the activities that inferred laws and principles by applying to various phenomena. On the contrary, the Korean curriculum dominantly used interpreting data and exploring activity, which made it plausible to not incorporate the deductive method to predict and explain the situation with a hypothesis or a theory. In such cases it is more appropriate to use the inductive method to discover a pattern or a relationship out of the collected data and to generalize it.

Appendix B presents a number of examples of earth science inquiry methodology. Hands-on activities using models in the U.S. textbook incorporated much of the abductive method. For example, there was an activity that asked students to explain the phenomena based on the similarity of the model with the real phenomena after making a model of convection currents. When students compared similarities or differences of the observed objects and produced generalization or discovered some patterns of data, they used inductive reasoning. One example of deductive method asked students to apply the principle of superposition to the actual geologic column, and determine a geological age (see Appendix B). The inductive method in Korean curriculum was used in interpreting data and experimental activities. For instance, experimental activities encouraged students to find a relationship between the volume of vapor and the temperature in the air based on their observations (see Appendix B). The Korean textbook used the abductive methodology to ask students to explain the difference of volcanic activities according to the type of plate boundaries by using interpreting data and an exploring activity. Also, the deductive methodology was utilized when applying the classification principle that was learned previously to classify the volcano types.

Pierce stated that all the ideas of science come from abduction (Hanson, 1958). Besides, Lawson (2005) argued that human being's reasoning in everyday context and scientific inquiry was operated by hypothetico-deductive way, which incorporates analogical reasoning, or abduction to spontaneously make hypotheses. They believed the importance of abductive reasoning for scientific inquiry. Especially, when researchers agree that the abductive method well represents the features of earth science inquiry methodology (Oh & Kim, 2005), and that it is one of the earth scientific reasoning abilities, results of this study suggest that inquiry activities included in the U.S. curriculum provided students with more opportunities to learn the earth scientific reasoning than the Korean curriculum. However, to practically teach the abductive reasoning in school inquiry activities, earth science curriculum ought to incorporate the inductive method to generalize based on observations and to appropriately distribute the deductive method to apply basic principles to specific cases of earth science.

As shown in Table 1, the hermeneutic method used in the U.S. and Korean curriculums was similarly distributed. Forestructures of understanding were dominantly used in both curriculums. One of the reasons is that students cannot approach inquiry objects without having preconception, foresight, and necessary to perform most of the inquiry activities. For instance, when students were asked to make a hypothesis about the cause of phenomena, they needed their preconception and foresight about the natural phenomena. The circular reasoning was often used in the inquiry tasks to understand an attribute or a tendency of objects coming from a relationship between the part and the whole. For example, in the U.S. curriculum, when talking about the role of convection in plate tectonics, students could understand the part of convection through a whole picture of plate tectonics. Students would then be able to grasp the whole figure of plate tectonics by understanding the part of convection. In this way, students could reason circularly. The circular reasoning found in the Korean earth science curriculum was frequently used in the inquiry tasks in order to predict a future tendency by, in part, understanding the present. One example was to predict the temperature change of the future by understanding how it would change through a short period of time and to measure a tendency of temperature change. This kind of hermeneutic method was used to find out a tendency in the interpreting data activities. Therefore, the circular reasoning was most often used in the Korean curriculum because it included more interpreting data activities (35.6%) than in the U.S. textbook (9.1%). The historical nature of human understanding was not used much in both Korean (6.96%) and the U.S. curriculums (2.39%). One of these reasons is that earth scientific concepts were not repeatedly used to explain a phenomenon of the earth in other inquiry activities found in the U.S. textbook. Rather, it is completed in one activity. For instance, the Holt curriculum used the concept of relationship between the color and the temperature of a star multiple times within one activity of the unit, rather than in other inquiry hands-on activities. Conversely, Korean earth science curriculum used the same concept multiple times in a number of inquiry activities, in which interpreting data was the main type of inquiry activity. That is, the Korean curriculum would use the concept of plate boundaries repeatedly in a number of inquiry activities across different domains, i.e., geology and oceanology when explaining the difference of the ocean floor in Atlantic and Pacific Oceans.

Historical Methodology

Regarding the historical methodology, this study found that both curriculums included adhering to the modern principles of uniformitarianism and constructing proper taxonomy. A key difference, however, was that Korean curriculum included more inquiry activities incorporated with the proper taxonomy construction; whereas the U.S. textbook provided more activities with the modern principle of uniformitarianism. Using the proper taxonomy constructions, the Korean curriculum encouraged students to classify or explain the cause in earth scientific terms. And, though the U.S. curriculum presented numerous hands-on activities making models, there were not many activities to practice classification. Both curriculums rarely utilized the place substituting for time in stage theorizing. One of the reasons for this result is that the activities to reason the continuous process of time by suggesting the place substituting for time was limited to activities that determine the relative ages by using rocks or fossils in both textbooks. However, the Korean curriculum included slightly more opportunities using the stage theorizing than the U.S. curriculum because it added an activity to relatively sequence the layers in geologic map. As part of the historical methodology, relic interpretation was incorporated in the activities to reason out the prior events through direct observation in the U.S. curriculum; whereas it was used in the activities to reason out the past formation process by indirectly observing the earth scientific phenomena or structures in the activity of interpreting data in the Korean curriculum (see Appendix B). Evaluating independent lines of inquiry for convergence was presented with low frequency in the Korean curriculum, but not at all in the U.S. textbook. One possible explanation is that there were not many opportunities that organized one earth scientific theory into several of the inquiry activities, and thereby producing independent research results that converged into the theory. The Korean curriculum used this method limited to independent results to converge on the heliocentric theory and plate tectonics. The U.S. curriculum mainly adhered to the modern principle of uniformitarianism in the activity of using models. An example of this feature asked students to explain the mantle convections of natural phenomena in the real world with the similar process to a model made in school experiments. Also, one example of constructing proper taxonomies is an activity to help students' reason out the cause and effect by properly classifying biomes. In the Korean curriculum, the method of constructing proper taxonomies was mainly used in the exploring activity or interpreting data activity. For instance, there was an activity that asked students to classify the type of volcanoes according to the type of plate boundaries on the premise that volcanic activities were different. An example of the modern principle of uniformitarianism is that when asking students to explain the phase change of the Venus with a viewpoint of heliocentric theory in the activity "Phase of the Venus", they explain it with the assumption that it is the same as the phase change of the Moon (see Appendix B).

Table 2a. The Relative Frequency in Earth Science Inquiry Methodology according to the Domains of Earth Science(Korea)

	Korean textbook (%)					
	Inquiry method	Environment	Geology	Meteorology	Oceanology	Astronomy
Inductive method	28.57	19.35	44.96	40.63	52.54	47.27
Abductive method	14.29	54.84	34.88	15.63	44.07	23.63
Deductive method	28.57	16.13	13.18	21.88	0	10.91
Not using any logical method	28.57	9.68	6.98	21.88	3.39	18.18
Total	100	100	100	100	100	100
Circular reasoning	10	9.09	8.22	20.45	21.25	18
Forestructures of understanding	65	87.88	80.82	73.86	65	72
Historical nature of human understanding	5	3.03	9.59	2.27	13.75	4.67
Not using any hermeneutic method	20	0	1.37	3.41	0	5.33
Total	100	100	100	100	100	100
Adhering to the modern principle of uniformitarianism	7.14	31.03	11.81	8.45	9.43	13.45
Place substituting for time in stage theorizing	0	0	3.47	0	0	0
Relic interpretation	0	0	12.50	0	0	0
Constructing proper taxonomies	28.57	31.03	38.19	21.13	33.96	21.85
Evaluating independent lines of inquiry for convergence	0	0	0.69	1.41	0	1.68
Not using any historical method	64.29	37.93	33.33	69.01	56.60	63.03
Total	100	100	100	100	100	100

Table 2b. The Relative Frequency in Earth Science Inquiry Methodology according to the Domains of Earth Science(U.S)

	U.S. textbook (%)					
	Inquiry method	Environment	Geology	Meteorology	Oceanology	Astronomy
Inductive method	15	54.55	38.30	35.14	41.67	18.52
Abductive method	45	24.24	31.91	37.84	58.33	57.41
Deductive method	15	18.18	25.53	24.32	0	11.11
Not using any logical method	25	3.03	4.26	2.70	0	12.96
Total	100	100	100	100	100	100
Circular reasoning	18.18	13.16	14.29	16.28	0	10.45
Forestructures of understanding	81.82	71.05	77.68	83.72	81.82	83.58
Historical nature of human understanding	0.00	0.00	3.57	0.00	0.00	4.48
Not using any hermeneutic method	0	15.79	4.46	0	18.18	1.49
Total	100	100	100	100	100	100
Adhering to the modern principle of uniformitarianism	5.56	0	23.36	5.26	35.71	26.56
Place substituting for time in stage theorizing	0	0	1.87	0	0	0
Relic interpretation	0	0	14.95	0	0	0
Constructing proper taxonomies	0	9.09	14.02	23.68	35.71	15.63
Evaluating independent lines of inquiry for convergence	0	0	0	0	0	0
Not using any historical method	94.44	90.91	45.79	71.05	28.57	57.81
Total	100	100	100	100	100	100

Earth Science Inquiry Methodology according to the Domains of Earth Science

Logical Inference Methodology

Korean Curriculum

The study found that Korean earth science curriculum used the abductive method most frequently in the domain of environment (see Table 3a&3b). One explanation is that when requiring students to think about the cause of environmental change or to predict the situation of the future, they mainly use abductive reasoning. Explaining the cause of a recent temperature change is one example of this type of reasoning (see Appendix B). Conversely, the inductive method was most frequently used in the domain of oceanology since there were several activities to induce the tendency or feature in interpreting data activities about ocean floors or ocean water. Comparison and classification of distinctive topography in the exploring activity with ocean floors is an example of inductive reasoning. The deductive method was most frequently used in the domain of inquiry method, but it was not utilized in oceanology. An example of the deductive method was demonstrated as an activity of earth science inquiry process when students were instructed to identify which inquiry steps were the activities written on the cardboard they picked. In this way, students were able to apply the principle of inquiry process into a specific case (see Appendix B). Finally, when comparing all domains by the percentage per the cumulative number of inquiry activities, geology represented a combination of inductive, abductive, and deductive methodologies (see Table 3a&3b). It stands to reason that this result was anticipated since 31.88% out of the entire inquiry activities was in the Korean earth science curriculum.

The U.S. curriculum

Regarding the inquiry activities in the U.S. curriculum, the inductive method was used most frequently in the domain of environment. One example asked students to draw a generalized conclusion after observing the extent those particles were removed, following a method to purify polluted water (see Appendix B). The inductive method was mainly used when identifying the similarity or attributes through observations in such experimental activities. The abductive method included in the U.S. curriculum was most frequently used in the domain of oceanology. One example asked students to determine why some parts of the ocean turned over and other parts did not (see Table 2). This type of abductive reasoning was primarily used when students made a hypothesis or brainstormed the cause of a particular phenomenon. On the other hand, the deductive method was most frequently used in the domain of geology. Based on the experiment of the deposition of sediment in a bottle, students applied the principle of the result into different cases, which were coded as deductive reasoning. When comparing the entire domains analyzed (see Table 3a&3b), both inductive and deductive methods represented the majority of geology, including a large number of inquiry activities, while the abductive method was widely utilized in the domain of astronomy.

Overall, this study found statistically significant differences between U.S. and Korean curriculums in terms of the feature of earth science methodology in each domain: The inductive method in Korean curriculum was most frequently utilized through activities inducing the attributes or tendencies of objects when interpreting data in oceanology; and the U.S. curriculum, mainly used the inductive method through activities of finding out the features of objects in the domain of environment. With high frequency, the abductive method was incorporated when predicting a situation of the future in domain of environment in the Korean curriculum, and when explaining the cause of a phenomenon in the model-based activities of the U.S. curriculum. Interestingly enough, the deductive method was rarely used in both curriculums, but in some instances the deductive method was applied to the principle of inquiry process into a specific case in Korean curriculum as well as applied to the principle of superposition in the U.S. curriculum. In both curriculums, the deductive method was not used at all in the domain of oceanology. A probable explanation is that oceanology did not offer a large number of inquiries and incorporated neither the abductive nor inductive methods with any frequency. When comparing the entire domains, both inductive and deductive methods were highly used in geology, which was common in both curriculums. On the other hand, the abductive method was frequently included in the domain of astronomy in U.S. curriculum, and in geology in the Korean textbook, especially since a number of inquiries in the domain of geology and astronomy dominated both curriculums.

Table 3a. The Percentage per Total Number of Inquiry Activities according to the Domains in Earth Science Inquiry Methodology(Korea)

	Korean textbook											
	Inquiry method (%)	No.	Env. (%)	No.	Geo. (%)	No.	Meteo. (%)	No.	Oce. (%)	No.	Astr. (%)	No.
Inductive method	2.90	4	4.35	6	42.03	58	18.84	26	22.46	31	37.68	52
Abductive method	1.45	2	12.32	17	32.61	45	7.25	10	18.84	26	18.84	26
Deductive method	2.90	4	3.62	5	12.32	17	10.14	14	0.00	0	8.70	12
Not using any logical method	2.90	4	2.17	3	6.52	9	10.14	14	1.45	2	14.49	20
Circular reasoning	1.45	2	2.17	3	8.70	12	13.04	18	12.32	17	19.57	27
Forestructures of understanding	9.42	13	21.01	29	85.51	118	47.10	65	37.68	52	78.26	108
Historical nature of human understanding	0.72	1	0.72	1	10.14	14	1.45	2	7.97	11	5.07	7
Not using any hermeneutic method	2.90	4	0.00	0	1.45	2	2.17	3	0.00	0	5.80	8
Adhering to the modern principle of uniformitarianism	0.72	1	6.52	9	12.32	17	4.35	6	3.62	5	11.59	16
Place substituting for time in stage theorizing	0.00	0	0.00	0	3.62	5	0.00	0	0.00	0	0.00	0
Relic interpretation	0.00	0	0.00	0	13.04	18	0.00	0	0.00	0	0.00	0
Constructing proper taxonomies	2.90	4	6.52	9	39.86	55	10.87	15	13.04	18	18.84	26
Evaluating independent lines of inquiry for convergence	0.00	0	0.00	0	0.72	1	0.72	1	0.00	0	1.45	2
Not using any historical method	6.52	9	7.97	11	34.78	48	35.51	49	21.74	30	54.35	75

Note. No.is the number of methods coded.

Hermeneutic Methodology

Korean Curriculum

The use of forestructures of understanding was dominant in the Korean earth science curriculum in all of the domains, especially prevalent in environment. For instance, when students found what the limestone in a lithosphere was made out of through inquiry activities about the carbon cycle, they approached the activity with the preconception about limestone and lithosphere. The circular reasoning and the historical nature of human understanding were used frequently in the domain of oceanology (see Table 2a & 2b). One explanation is that oceanology often incorporated the circular reasoning when determining if a pattern existed in the activities of interpreting data. For example, students would use circular reasoning to identify a pattern of the temperature change according to the latitude (see Appendix B). Moreover, the historical nature of human understanding was significant in the domain of oceanology because the concepts about plate tectonics, which was first learned in Earth Science 1 was repeatedly used and thus reinforced. When comparing the entire domains (see Table 3a&3b), the forestructures of understanding and the historical nature of human understanding were used with more frequency in the domain of geology since this domain included a large number of inquiry activities. Finally, the circular reasoning was also used with high percentage in the domain of astronomy.

U.S. Curriculum

The U.S. curriculum used the forestructures of understanding with high frequency across all the domains, but especially in the domain of astronomy. When students formed a hypothesis about the relationship between the colors of star and the temperature, they used their preconceptions and foresight acquired through experiences (see Appendix B). The difference between the Korean curriculum and the U.S. activities was that the latter used circular reasoning dominantly in the domain of inquiry method, which was not used in oceanology. An example of circular reasoning in inquiry method asked students to identify a pattern of rock layers in an activity in which students first predicted and illustrated rock layers based on their observations of core samples. To accomplish this task, students needed to circularly reason both a part and a whole of the rock layer's pattern (see Appendix B). The historical nature of human

Table 3b. The Percentage per Total Number of Inquiry Activities according to the Domains in Earth Science Inquiry Methodology (U.S.)

	U. S. textbook											
	Inquiry method (%)	No.	Env. (%)	No.	Geo. (%)	No.	Met. (%)	No.	Oce. (%)	No.	Astr. (%)	No.
Inductive method	6	3	36	18	72	36	26	13	10	5	20	10
Abductive method	18	9	16	8	60	30	28	14	14	7	62	31
Deductive method	6	3	12	6	48	24	18	9	0	0	12	6
Not using any logical method	10	5	2	1	8	4	2	1	0	0	14	7
Circular reasoning	8	4	10	5	32	16	14	7	0	0	14	7
Forestructures of understanding	36	18	54	27	174	87	72	36	18	9	112	56
Historical nature of human understanding	0	0	0	0	8	4	0	0	0	0	6	3
Not using any hermeneutic method	0	0	12	6	10	5	0	0	4	2	2	1
Adhering to the modern principle of uniformitarianism	2	1	0	0	50	25	4	2	10	5	34	17
Place substituting for time in stage theorizing	0	0	0	0	4	2	0	0	0	0	0	0
Relic interpretation	0	0	0	0	32	16	0	0	0	0	0	0
Constructing proper taxonomies	0	0	6	3	30	15	18	9	10	5	20	10
Evaluating independent lines of inquiry for convergence	0	0	0	0	0	0	0	0	0	0	0	0
Not using any historical method	34	17	60	30	98	49	54	27	8	4	74	37

Note. No.is the number of methods coded.

understanding was rarely used only in the domain of astronomy and geology. When comparing the entire domains (see Table 3a & 3b), the forestructures of understanding and the circular reasoning were most used in the domain of geologybecause of a large number of inquiry activities offered.

When comparing both of the curriculums to each other, this study found that the forestructures of understanding was utilized most frequently in all of the domains, and in both textbooks. While the Korean curriculum used the circular reasoning with the highest frequency through interpreting data activities in oceanology, which offered to reason a relation between a part and a whole, the U.S. textbook mainly used the circular reasoning in activities that compared the patterns that students predicted and drew from to a real figure in the domain of inquiry method. The historical nature of human understanding was used with high frequency in the domain of oceanology in Korean curriculum, it was rarely utilized in astronomy and geology in the U.S. curriculum. When comparing the entire domains (see Table 3a&3b), the forestructures of understanding was most readily used in the domain of geology in both curriculums, while the circular reasoning was most widely used in astronomy in the Korean textbook and in geology in the U.S. curriculum.

Historical Methodology

Korean Curriculum

The constructing proper taxonomies were most used across all the domains followed by the adhering to the modern principle of uniformitarianism (see Table 2a & 2b). The domain of environment, in which the modern principle of uniformitarianism was most used, included many activities predicting the future change of Earth's environment based on the assumption that it would be similar to the present state of Earth's environmental changes. The constructing proper taxonomies were most used in activities that offered students an opportunity to rationalize the environment's state or process the formation in geology. For example, students were asked to classify the feature of deposition by using earth scientific terms related to the deposition structure and to explain the environment of deposition through activities that made unique deposition structures. The relic interpretation and the place substituting for time in stage theorizing were used only in the domain of geology. For instance, the place substitute for time was taught by informing students that the formation sequence of an ocean crust was via the distribution of ocean crust age. In addition, the relic interpretation was presented through a series of activities in which students reasoned the moving direction and the formation processes of an ocean crust after indirectly observing the relic of ocean crust (see Appendix B). The evaluating independent lines of inquiry for convergence were most utilized in astronomy. For instance, researchers coded the phase change of Venus as one of the research results that supported a heliocentric theory through interpreting data activity about a phase of Venus (Appendix B). When comparing the whole domains (see Table 4), all of items in the historical method, except evaluating independent lines of inquiry for convergence, were dominant in the domain of geology.

U.S. curriculum

Throughout the activities in the U.S. curriculum, adhering to the modern principle of uniformitarianism and constructing proper taxonomies were most used in the domain of oceanology. Specifically, these two features were used in the activity of using a model in which students assumed that a model in the activity was similar to the real phenomena and thus explained the cause of the natural phenomena using earth scientific terms. That is, students used the modern principle of uniformitarianism in which the process of experiment is similar with the real natural phenomenon as they developed an understanding of and rationalized why some parts of the ocean did not turn over in the density current (see Appendix B). Furthermore, when this activity asked students to explain why no density current occurred by using appropriate earth scientific terms, it has an activity of constructing proper taxonomies. This study found that the relic interpretation and the place substituting for time in stage theorizing were only used in the domain of geology, just as in the Korean curriculum. In this case, the activity to determine the relative age after comparing several outcrops in different places required students to use the place substituting methodology for time in stage theorizing. An activity of finding out the past events through a number of investigative observations of the present objects in an experiment about deposition structure was used as part of the relic interpretation. However, the methodology of evaluating independent lines of inquiry for convergence was not utilized in any of the domains. When comparing the entire domains, all the historical methods were included in the domain of geology as was the case in the Korean curriculum.

When comparing the domains between Korean and the U.S. curricula, the Korean curriculum used with high frequency the methodology of adhering to the modern principle of uniformitarianism in the domain of environment, which also included a number of activities to predict the future environment of the earth. It also used with high frequency the constructing proper taxonomies in the domain of geology—including activities to reason the environment or process the formation by using appropriate earth scientific terms. The U.S. curriculum incorporated the constructing proper taxonomies in the domain of oceanology, which included many activities to explain the oceanic phenomena by using models. The place substituting for time in stage theorizing and the relic interpretation were only used in the domain of geology in both curriculums. The evaluating independent lines of inquiry for convergence were used with high frequency in the domain of astronomy, but only in the Korean textbook. Overall, the historical method was most commonly used with a high percentage in the domain of geology in both curriculums. One of the reasons is that the domain of geology included a large number of inquiry activities and many activities that sought to understand the past based on investigations of the present earth scientific phenomena, which is a characteristics of geology. As shown in Table 3a&3b, the U.S. textbook incorporated a greater percentage of earth scientific methodologies than in the Korean curriculum for most of the domains. A plausible explanation for this is that even though the U.S. curriculum had a small number of inquiry activities, it offered a variety of features of earth science methodologies in one activity. This result suggests that the Korean curriculum diversifies an inquiry activity more to accommodate the very characteristics of earth science methodology. After analysis of the results, this study was left with the impression that there was a tendency about the analysis framework; that is, the deductive method in logical inference method and forestructures of understanding in the hermeneutic method were simultaneously used. This may be because the deductive reasoning applied principles or laws into concrete objects, and the principles or laws were deemed as the preconception in forestructures of understanding. For example, scientists often reason deductively by applying the principle of superposition to the specific cases and determine a geologically relative age. At the same time, we approach inquiry objects with a preconception of the principle of superposition. Therefore, this is part of the forestructures of understanding. The hermeneutic method was often incorporated when students explained the cause of phenomena in inquiry activities. This study also found that the abductive method was frequently used with the hermeneutic method together because the method was used to explain the cause of the phenomena.

CONCLUSION AND IMPLICATIONS

In this study, researchers analyzed inquiry activities of earth science textbooks with the analysis framework of earth science inquiry methodology to see how frequently earth science methodologies are reflected in prevalent textbooks used in Korea and in the U.S. In the logical inference method, the inductive method was incorporated most often in the Korean curriculum because a large proportion of inquiry tasks asked students to discover a tendency or identify a generalized principle after comparing and classifying through the activities of exploring or interpreting data. The abductive method was used a little more than the inductive method in the U.S. curriculum because the steps of forming a hypothesis were included in the beginning of most inquiry activities, and many activities asked students to explain a phenomenon based on the realized similarity between models and actual natural phenomena. The deductive method was rarely used in both curriculums. When researchers agreed that the abductive method represents the features of earth science inquiry methodology well (Oh & Kim, 2005), inquiry activities in the U.S. curriculum provided students with more opportunities to learn earth scientific reasoning than in the Korean curriculum.

This study found that the use of the hermeneutic method in both curriculums was similar. The forestructures of understanding was incorporated overwhelmingly in both curriculums because students needed to have preconceptions, foresights, and fore-having to perform most of the inquiry activities. The historical nature of human understanding was rarely used in both curriculums and even less in the U.S. textbook. One explanation for this pattern would be that inquiry activities in the U.S. curriculum were mainly performed as a type of hands-on activity in which students worked on one subject. Therefore it is rare that students repeatedly used one concept through several activities. In the historical method, the adhering to the modern principle of uniformitarianism and constructing proper taxonomies are dominantly used in both textbooks. Inquiry activities in the Korean curriculum incorporated more activities on the constructing proper taxonomies, whereas the U.S. curriculum used more of the modern principle of uniformitarianism. The place substituting for time in stage theorizing was an only used in activity to determine a relative age using rocks or fossils in both textbooks. The relic interpretation was incorporated in the activity to rationalize the prior events through direct observations in the U.S. curriculum, whereas the Korean textbook used it to reason out the past formation process by indirect observation through the activity of interpreting data. The evaluating independent lines of inquiry for convergence were rarely incorporated in the Korean curriculum and not at all in the U.S. curriculum since both curricula only included a few inquiry tasks in which one earth scientific theory was used in several different inquiry activities that produced independent investigation outcomes and converged into one conclusion. Overall, this study concluded that the features of earth science inquiry methodology were more incorporated in the Korean curriculum than in

U.S. curriculum in terms of its variety and entirety. This result seems quite desirable, which is to say that earth science activities in the Korean textbook appropriately reflected the overall earth science methodology and provided students with more opportunities to develop their earth scientific literacy. However, the results also showed that abductive reasoning, the historical nature of human understanding, and the evaluating independent lines of inquiry for convergence needed reinforcement.

The comparison of the distribution of earth science methodology according to the domains between the two curriculums showed that each had appropriate distributions in most domains. However, the deductive method in logical inference was not used in the domain of oceanology within both textbooks, and oceanology in the U.S. textbook did not include the circular reasoning and the historical nature of human understanding in hermeneutic method. Therefore, it is recommended that inquiry activities of this domain incorporate various hermeneutic methods need to be further developed. When comparing the entire domains, both curriculums frequently used most of the features of earth science methodology in geology. The U.S. textbook tended to use the abductive method in astronomy, whereas the Korean curriculum tended to use the circular reasoning and evaluating independent lines of inquiry for convergence in astronomy. This pattern seems plausible since geology and astronomy included a larger number of inquiry activities than any other domains. It is widely understood that in an earth science curriculum the importance of geology and astronomy are emphasized in high school earth science. However, as scientific literacy and science-for-all are emphasized in the goal of science education in the 21st century, the importance of earth environment education is not to be ignored. Therefore, the domain of environment needs to be reinforced with the features of earth science methodology in both curriculums. Given the fact that the U.S. curriculum included a small number of inquiry activities—various features of earth science methodology, it is suggested that the Korean curriculum needs to develop inquiry activities in which one activity can incorporate various features of earth science methodology, rather than providing a large number of different activities.

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Appendix A. The Inquiry Analysis Framework based on the Features of Earth Science Inquiry Methodology (Kim et al., 2005)

	The features of earth science inquiry methodology
Logical inference methodology	· **Inductive method**: the process to discover a law as a result of observing and exactly describing controlling state of affairs and phenomena. (Example) 1. In various experiments, carbon was exposed to various pressures in the absence of oxygen at a temperature of 1000℃ 2. In all experiments in which the pressure exceeded 55 kbar, and only under these conditions, diamond was produced. 3. If carbon is exposed to pressures of over 55kbar in the absence of oxygen and at 1000℃, diamond will be produced. · **Abductive method**: the process to infer a principle, a fact, or a law and yield or newly construct explanatory hypothesis to explain the resulting state of affairs. (Example) 1. Diamonds were found in volcanic pipes in South Africa. 2. Diamonds are produced only from carbon and carbon compounds when the temperatures reach at least 1000℃ an when the pressures are at least 55kbar. 3. In the formation of the volcanic pipes, material was brought up from depths where the pressure of at least 55 kbar is obtained. · **Deductive method**: the process to produce a statement regarding the resulting state of affairs from a universal law or a general assertion. (Example) 1. At pressures of over 55kbar and at temperatures of over 1000℃, carbon in the absence of oxygen will change into a diamond. 2. In an experiment, carbon is subjected a pressure of 80 kbar and a temperature of 1200℃. 3. In the experiment a diamond will be produced.
Hermeneutic methodology	· **Circular reasoning:** a line of thinking that the meaning of its parts is understood from its relationship to the whole, while our conception of the whole is constructed from an understanding of its parts. (Example) Our understanding of a region is based on our interpretation of the individual outcrops in that region, and our interpretation of an individual bed within an outcrop is based on our understanding of the sediments and structure that make up that bed. · **Forestructures of understanding:** a tendency to approach our object of study with our preconception and theory, foresight which is our idea of presumed goal of our inquiry and our sense of answer, fore-having which is a set of implements, and skills and institutions we bring to the object of study. (Example) When scientists approach the Western Codillera with concepts like ophiolite complexes and accretionary terranea, the concept will affect what they see in the field. · **Historical nature of human understanding**: a recognition that our original goals and assumptions result in certain facts being discovered rather than others, which in turn leads to new avenues of research and sets of facts. This particular prejudgment we start with has a lasting effect. (Example) Any scientist can name areas of potential importance that do not get pursued because of the lack of time and resources or the lack of sufficient commitment on the part of the scientific community. As these decisions get multiplied over the decades the body of scientific knowledge comes to have a strongly historical component.

Appendix A. Contionusly

Historical methodology	· **Adhering to the modern principle of uniformitarianism**: a method for a scientist to examine small, steady processes of change in the present, then extrapolate their effects over geological time and predict or reason either forward or backward in time. (Example) Just as the method Lyell had used to interpret rock strata, Darwin applied this method to life by extrapolating the process of selective breeding to infer the effects of natural selection over time. · **Place substituting for time in stage theorizing:** the way that scientists assume that geologic objects in different stages can be arranged by an order of time. (Example) When three types of atolls: fringing reef, barrier reef, and atoll was observed in the present at different places, it is assumed those are the historical consequence of slowly sinking islands over different periods of time. · **Relic interpretation:** the way to interpret and reason historical changes or new tendencies which relics of past event have, when an object doesn't have observable clues about their assumed derivation. (Example) Since it is impossible to directly observe bombardment of a meteorite, scientists can approximately assume the geological history of Moon by investigating astrobleme remaining on the surface of it. · **Constructing proper taxonomies**: the method to use explanatory categories which can connote a causal reasoning (Example) The plate tectonic has developed, supported by using descriptive categories such as ophiolite, spreading center, convergent boundary, and arc volcanics, which connote a causal reasoning. · **Evaluating independent lines of inquiry for convergence:** the method to evaluate the extent to which common answers converge by examining various and independent lines of inquiry results. (Example) A continent drift theory could be admitted when independent lines of inquiry results such as magnetic stripe laid down symmetrically, magnetic anomaly mapping, and the drift of a magnetic pole converged to common consequence of the continent drift.

Note: The examples presented in the table are adapted from Ault (1998), Engelhardt & Zimmermann (1982), and Frodeman (1995).

Appendix B. Examples of Comparative Analysis Using the Framework of Earth Science Inquiry Methodology

Domain	U.S. textbook		Korean textbook	
	Content of inquiry activities	**Result and source of analysis**	**Content of inquiry activities**	**Result and source of analysis**
Geology	How Do You Stack Up? ·Which is the oldest layer in your column? ·Which rock layer is the youngest? ·How do you know?	· To decide the geological time sequence by applying the principle of superposition into the actual geologic column - *deductive method* · To decide the geological time sequence by comparing the individual outcrop with the whole outcrop - *circular reasoning* · To approach inquiry objects with preconception of the principle of superposition - *forestructures of understanding* · To explain the past earth scientific phenomena based on the present earth phenomena - *adhering to the modern principle of uniformitarianism* · To find time sequence of the past occasion by exploring the present deposition of different place - *place substituting for time in stage theorizing*	Distribution of the Oceanic Crust Age ·What is the age of the oldest rock composed of the oceanic crust? ·Does the distribution of Oceanic crust age have a pattern in direction? If so, what is it?	· Skill required to read a map that represent the earth scientific data - *forestructures of understanding* · To replace place with time by understand the age of oceanic crust and the distribution of oceanic crust – *stage theorizing* · To discover a pattern through interpreting data. - *inductive method* · We can discover a pattern of objects among the relationships between a part and a whole - *circular reasoning* · Students need skills to interpret earth scientific data - *forestructures of understanding* · Students can reason the formation process after observing the relic of Oceanic crust-*relic interpretation*
Meteorology	Under Pressure ·Explain what atmospheric factors affect how your barometer works.	· To explain the cause of phenomena based on the prior experience- *abductive method* · To approach the problem with preconception about relationship between air pressure and factors of atmospheric component - *forestructures of understanding*	Relationship between vapor Content and Temperature in the Atmosphere ·What is the relationship between temperature and vapor content to be contained in a given volume of air?	· Students generalize the relationship between vapor content and temperature based on observation - *inductive method*
Oceanology	Up from the Depths ·What reasons can you give to explain why some parts of the ocean do not turn over in the spring while some do?	· To explain the cause why some parts of the ocean do not turn over using experiment models - *abductive method* · To explain the cause on the assumption that the process of experiment is similar to real nature phenomena - *adhering to the modern principle of uniformitarianism* · Needs of preconceptions like density and salinity and skills of interpretation - *forestructures of understanding* · Explanation of the cause of phenomena by using the concept of density, an earth scientific term – *taxonomic system*	Distribution of the Surface Temperature in The Ocean ·How is the surface temperature in the ocean different along with the latitude?	· We discover the tendency through interpreting data - *inductive method* · We infer a relationship between a part and a whole in temperature distribution to discover the tendency of temperature increasing along with the latitude - *circular reasoning*

Appendix B. Contionusly

Astronomy	Red Hot, or Not? ·How are the color and temperature of a star related?	· To form a hypothesis about the relationship between color and temperature of a star- *abductive method* · To approach inquiry objects with insight to predict an answer - *forestructures of understanding*	Phase Change of the Venus ·Which of the Venus orbits do you think has to be observed in the way of actual phase and size change between orbits in heliocentric and geocentric theory?	· Students can explain phase change of the Venus from a perspective of heliocentric theory assuming that it is the same as Phase change of the moon - *adhering to the modern principle of uniformitarianism* · Students can evaluate phase change of the Venus as one of the research results supporting the heliocentric theory - *evaluating independent lines of inquiry for convergence*
Environment	Clean Up Your Act ·Did the filtration method remove all of the particles from the polluted water? Explain!	· To draw a generalized conclusion from observed results - *inductive method*	A pattern of Recent Global Temperature Change ·Discuss the cause of global temperature changes, and predict the temperature change of the future	· To explain the cause of global temperature changes - *abductive method* · Based on the discovered pattern of the recent global temperature change, students can predict the future temperature change - *adhering to the modern principle of uniformitarianism*
Inquiry method	Using Scientific Methods ·Look at the pattern of rock layers in each of your core samples. Think about how the rock layers between the core samples might look. Then, make a diagram of the rock layers.	· To circularly reason the individual and the whole pattern of rock layers to figure out the pattern of rock layers- *circular reasoning*	Inquiry Process in Earth Science ·Which step does the activity written on the card fall on?	· To apply the procedure of inquiry methodology step to the specific cases - *deductive method*