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Exploring Korean Pre-service Elementary Teachers' Scientific Inquiry Using the Science Writing Heuristic Template

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Abstract: This study aimed to investigate the characteristics of pre-service elementary teachers' understanding about scientific inquiry in terms of designing exploration and reasoning that is used to formulate explanations based on evidence. The research context was an open inquiry with using the Science Writing Heuristic (SWH) template in which participant students were not provided with inquiry questions. As data, lab. 39 pre-service elementary teachers participated in this study while taking their science methods course. Analyses of the reports were framed by the cognitive processes of inquiry (Chinn and Malhotra, 2002) and each report was coded and analyzed by the framework of inquiry (Tytler and Peterson, 2004). Results showed that groups' works that utilized the SWH template encouraged the participants to interact each other about scientific inquiry. They came up with more relevant and testable questions for their scientific inquiry. It implicates that children will be able to have chances of testing their own questions more properly by using the SWH template in science classes just as the participants did in this study. The use of the SWH template would help pre-service teachers to teach appropriately how to test inquiry questions to their students in the future. Discussion was made to figure out the characteristics or Korean pre-service elementary teachers' understanding about scientific inquiry.

Keywords: scientific inquiry, cognitive process, scientific reasoning

Introduction

The goals of inquiry, based on the Inquiry NSES (NRC, 2000), are summarized as two. Through school science, students should learn how to do scientific inquiry and to develop an understanding of scientific inquiry. These two goals are hardly pursued simultaneously in current practices of school science. For example when students memorize very higher level of scientific knowledge to succeed in the written tests, they might fail to make their own testing questions and to solve ill-structured problems by generating explanations from evidences. Huge gaps or discrepancy can be found in between a level of knowledge possessed by students and their cognitive process level. As scientific knowledge is to be results of doing science and school science is supposed to work in that way, the level of possessing knowledge may well be consistent with cognitive process reached by students. The discrepancy suggested that students learned science by memorizing abstract science jargons rather than by doing science.

Knowing scientific knowledges means using them. In order to reach the status of knowing, people should learn what the scientific knowledge means and experience how it is produced. It is indeed correlated with cognitive process including scientific reasoning, making their own questions, and formulating their own explanations during making students' own meaning.

Unfortunately, school science in Korea has not been successful in making students struggle with provoking cognitive processes through scientific inquiry. The Science Writing Heuristic template has been adapted during past three years in science teaching methods course for the teacher education program by the author. The elementary pre-service teachers in this study experienced scientific inquiry with the SWH template for one semester course. It has gone through lots of trials and errors and ended up with proper strategies by the end of the semester. This study was a reflection of the final SWH reports of these students in that course.

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In this study, there are two research contents:

l. Features of scientific inquiry revealed in the SWH template which participant pre-service teachers worked and reported in their practicing elementary science experiments were explored qualitatively

2. What scientific inquiry means in educational purpose of school science was reconsidered.

Theoretical Framework

What can science education suggest teachers to do in their classrooms in order to move toward providing students with 'scientific practice' through their classes? Doing science is more like the skillful exercise of a repertoire of 'craft skills' than the following of an algorithm as Polanyi (1958) and Ravets (1971) asserted. In teaching children science, we are helping them to internalize the procedures and standards of scientific community. We are again assisting the child to construct for herself a mental representation of the scientific ways of working judging (Millar, 1989). It is because the training of scientists involves the process of coming to internalized these tacit canons of procedure and judgment.

The Science Writing Heuristic (SWH) focused on writing about science and writing scientifically. Hand et al. (2006) proposed that the SWH covered a scheme of scientific work with an emphasis on argumentation and inquiry organizers. With this science writing, students can learn and experience of scientific practice which consists of questioning, making hypothesis, doing experiments, finding evidences and making claims. This type of science activity is quite student-oriented and open exploratory activity.

Testing is an easy step of school science experiment. However through in-depth analysis of science class by observing elementary science classes, it is not easy to catch the scene describing students' own testing. Rather students follow and mimic the textbook experiments and fill out the worksheet. Mostly they copied the best students' answer in their group. They seemed to believe that there was an answer even in filling out the blank with the given task of 'Write what you observed'. During the author's observation of 4th graders' science class, it was found that two students in a group were not writing the worksheet and waited for so. The experiment was simple observation of color changes before and after the chemical reaction. The author asked them why they were not doing anything. They said they waited for the group leader finished writing answers in the blank in order to copy them. In fact, the color changes were not done perfectly same as textbooks said in that activity. The group leader wrote what she memorized from the textbook rather than what she observed. What school science are supposed to do in the name of scientific experiment are hardly real.

Based on the episode, scientific practice is at least not an activity to let students follow the directions and ignore any mistake or errors. Rather it should encourage students to define the different results and discuss them focusing on what they have known and newly found. In science practice, errors and wrong answers are good starting point of authentic sciencing.

In such an open exploration context of science practice, Tytler and Peterson (2004) studied scientific reasoning of elementary students. They characterizing the level of processing, dealing with competing knowledge claims and response to anomalous data which presented in elementary students' classroom dialogue. A large part of the program of science class tried to promote scientific reasoning. In order to achieve the purpose, teachers conceptualize and develop strategies for enhancing children's scientific reasoning. More importantly teachers needed to experiences representing scientific reasoning themselves.

In science education, characters and features of school science inquiry have been searched and explored in many ways for each researcher. At the international symposium (Abd-El-Khalick et al. 2004), researchers in science education made a list of jargons and phrase for describing scientific inquiry (Grandy and Duschl, 2007).; posing questions, refining questions, evaluating questions, designing experiments, refining experiments, interpreting experiments, making observations, collecting data, representing data, analyzing data, relating data to hypotheses/models/ theories, formulating hypotheses, learning theories, learning models, refining theories, refining models, comparing alternative theories/models with data, proving explanations, giving arguments for/against models and theories, comparing alternative models, making predictions, recording data, organizing data, discussing data, discussing theories/models, explaining theories/models, writing about data, writing about theories/models, reading about data, reading about theories/models.

This list interestingly included cognitive, social, and epistemological elements (Grandy and Duschl, 2007). For instance, writing about scientific theory is cognitive task and at the same time it can ask students to do societal judgment (Norris and Phillips, 2005). It is because writing for readers means that author need to possess delicate belief about what readers' belief and motivational structures are. If they fails to define something regarding readers, readers will not move and change their belief, and even worse they won't concentrate on the writings. Therefore this task needs in some point of view epistemological judgment and reasoning of students. In summary this list is parts of 'authentic inquiry' but all of it can be included in school science of real world. What are the best characters of 'school science inquiry' would be one of the most important assignments for science education researchers.

What experiences were provided for learners through inquiry occurred in school science? There is similar to the above but differentiated list of school science inquiry by Grandy and Duschl (2007). It focused on what learners should learn in school science inquiry.; Learners are engaged by scientifically oriented questions.; Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions; Learners formulate explanations from evidence to address scientifically oriented question.; Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.; Learners communicate and justify their proposed explanations.

This list can be considered when designing immersion program of long-term inquiry curriculum in the view point of learner-centered classroom environment. Considering limitation of physical environment and covering given national curriculum bound in school science, it is hardly said that authentic inquiry should be implemented in school. Still we can try to find the way of overcoming such impediments and propose feasible way of doing science. In that context, school science inquiry provides students with opportunities of formulating and evaluating explanations from evidences and actively participating at the scientific practice and discourse(NRC, 1996; McNeill, 2011). Science for students is more than telling concepts and facts, and includes thinking and reasoning. It is essentials to accumulate concrete illustration and experiential evidences to show practice and reality of school science inquiry at this moment.

Methods

(1) Research context

The investigation for this study occurred in the elementary science methods course for Junior year students of teacher pre-service university. During the class, the SWH template was adapted for students. It has seven questions including my question, my beginning understanding, tests to answer my questions, finding when I tested, my claims, my evidence and reflections.

A lecturer provided materials and let students do their own inquiry from generating questions to claims. Most experiment materials were from elementary science textbooks. After proceeding 9 periods of using the SWH template without any specific strategies but group questioning during the semester, the last lab. reports were collected for this research. Group questioning strategy is simply encouraging students to share their ideas and coming up with one compromising test question in each group work.

Task

Candles, lighters for lab., and different sized bottles with wide mouth were provided for students. What will be independent variables and dependent variables can judge the hypothesis of student group. Most cases of groups selected a big bottle and a small one. They observed differences of duration of candle's lighting covered by two different sized bottles. It is very typical experiment in elementary level science.

(2) Data Collection and analysis

Thirty nine collected the SWH template reports were analyzed according to cognitive processes of inquiry (Chinn and Malhotra, 2002). Out of 39 enrolled students, 21 were female and 18 male. Chinn and Malhotra (2002) categorized inquiry into authentic inquiry, simple experiment, simple observation, and simple illustration. And they defined cognitive process for each category and developed the framework to apply for analyzing textbooks. In the next step, cognitive process of participants presented in their reports were evaluated by the frame of Tytler and Peterson (2004) in three aspects of nature of exploration, level of processing, and response to anomalous data.

Results

Descriptions of changes in students' activity

Students worked lab. works in groups of 5or 6. Students more interacted with each other than in the first period of this class. When students generated their own individual test question in the first period, they didn't have much attention on group work including interacting their group members. Even most of time they searched the book or information. Their talks during the lab. were mostly on private chatting talks. They did not have much attention on the test and experiment either. One or two leader students in each group were only members working on the test. The rest of members in groups were just waiting for their finishing filling out the SWH sheet in order to copy them. This scene, interestingly, was frequently found in elementary students during my observation of elementary science classes.

At the last period of the course, group questioning strategy was adopted properly. Students started to make a test question as one group question. The whole situation was changed. Instead of having private talks, students in groups conferred with the test questions and methods and their verbal interaction and engagement on the lab. was even higher than the previous period. Each member of a group took participation on the task and was involved very actively.

Based on a capsule analysis of 39 students' lab. reports compared to the first submitted reports, the changes were quite visual. There was only one identical test question found at the first period among groups. Considering using quite simple equipments and materials, various questions in the last period were rather unusual. It is interpreted that all students in groups were involved in their own questions and testing.

Various test questions with same and simple experiment materials

Thirty nine students were provided with simple materials for their own test. They were candles, lighters for lab., and different sized bottles with wide mouth. They were asked to make their own test questions to be answered by the experiments using these given materials and devices. The list of questions found in 39 students is in Table 1.

There were differently dictated questions with the similar meaning as well. For instance, Q2 and Q3 are similar to each other. However Q2 has less clear description of variables for the test. In the elementary text book, the test questions were either Q2 or Q3. Even students in Q2 and Q3 tested the same way with ones in Q1.

In Q1, comparing the volume of bottle and burning time were quantitatively compared, which is not mentioned in the textbook. Even Q4 and Q5 were very creative and unique test questions comparing with typical activity in the textbook.

Table 1. Students' test questions (N=39)

Test Questions	Number of Students
"Is the time duration of combustion of a candle linearly proportional to the size of bottles?" (Q1)	22
"Air will affects on candle burning. We can find proportion rate between amounts of air and duration time of burning." (Q2)	1
"Is air related to time of burning candle?" (Q3)	4
"Does the number of candles in a bottle affect on their combustion time?" (Q4)	6
"If the bottle cover the burning candle not in tight but with some opening at the bottom, what will happen?" (Q5)	6

At the beginning of this course, students' test questions were identical to one another. There were only one or two questions in the SWH template reports. With active interaction among students in the last period, there found to be a variety of testing questions. It is an evidence to support that at the beginning of this course students copied their question from each other and it came up with one type of question. They were involved themselves in the right way of inquiry or testing at the last period.

During the discussion on generating a group question, they needed to select the best one. Therefore they employed the rule for selecting the best question of 'whether it is testable or not?'. They were asked to make their own claims from the test. If they have a researchable but not tested by means of given materials and equipments, they would face the improper claims without any test data. For example, how much oxygen will be needed for a candle combustion is very researchable but with limited materials it can not be tested.

In terms of coherence between questions and claims, few of reports in the first period had questions and claims coherent. The claims are supposed to respond to the questions. But in the last, most of students succeeded in making their questions coherent with claims.

Nature of exploration

The way students coordinated explanations with evidence is named as nature of exploration. Tytler and Peterson (2004) provided the categories for nature of exploration dimension with three levels: Level 1 is ad hoc exploration where no systematic observations or comparisons are made, or use of a guiding exploratory purpose. Exploration at this level interpretation that lies close to observable entities.; Level 2 is inference searching. The inference could be about relations between variables, or about theoretical ideas.; Level 3 is hypothesis checking. Explorations have a recognizable hypothesis driving them. Exploration at this level is theory led, but this level is theory led, but does not necessarily separate variables.

Table 2. Profile of levels of nature of exploration

Levels	Number of Students
1. Ad hoc exploration	2
2. Inference searching (Using inference)	29
3. Hypothesis checking (Checking/proving hypotheses)	8

By this coding framework, the level of nature of exploration for 39 students was resulted in Table 2.

In the first period, lab. reports indicated that students had a random focus when exploring a given form of experiment and following the steps. They just did something randomly and followed what others did. It is just like observing flowers with some fascination as saying out loud 'Wow!'. In the last reports, it was found that students moved to inference searching. Yet there was no drastic change to hypothesis checking level. Students actively play with various independent variables and looked at features of combustion of candle. They put up with various questions. Even with a similar test question, there were found two different test methods. For instance, with a question of 'Is amount of air related with burning time?', there were two test method: one used a big and a small bottle to check the time duration of candle burning in order to check relatively short or long. And the other intentionally two different sized bottles. One is five times bigger volume than the other. They tried to check whether the exact proportion of time duration of one and the other is 5 vs 1. The transformation of data were quite differentiated among students. In pre, only one and identical form of data table was reveal in all lab. reports. Students, in post, compared candle burning in pairs based on some factor of interest. An example of Ad hoc exploration was occurred in a group of Q 5. Two students only described what happened when they tested without any data providing and any focus on their test question.

Level of processing

The depth of processing is the extent to which students generated explanations that went beyond the data. In level of processing, Tytler and Peterson (2004) suggested three categories of description of phenomena, pattern identification, and explanations. Based on the pre and the post results, Table 3 was found after coding students' lab..

Most of students identified the generalized characteristics of combustion and relations between size of bottles and burning time duration. Still many students focused on the finding patterns not explanations. In case of Q5, students presumed that with some opening at the bottom of the covered bottle, air circulation would keep a candle burning. However the results was quite opposite. The burning candle was out quicker than the tightly covered one. They stated what they found without further discussion and proper explanation.

Responses to anomalous data

Students' responses when confronted with evidence that contradicted their explanations were analyzed. As Tytler and Peterson (2004) proposed, in responses to anomalous data there can be two categories of non-acknowledgement and acknowledgement in preliminary sorting.

In the first period, most students ignored anomalous data. But in the last, 29 of 39 acknowledged the anomalous data and 10 of 39 extended to explanation modification. Nine students proceeded their own re-

Table 3. Profile of levels of processing

Levels	Number of Students
1. Description of phenomena	3
2. Pattern identification	28
3. Explanation	8

test individually for the refinement of their claims and evidences. In the study of Lee et al. (2012), SWH reports by 115 pre-service teachers were examined in terms of coordination of theory and evidences. They tried to propose four types of coordinating theory and evidences. It, however, ended up with the finding of that active coordinating process was not frequently among their reports. It is quite similar to this study.

Cognitive process in authentic inquiry in school science inquiry but not in a whole set

Referring to Chinn and Malhotra (2002). there seems four different types of reasoning tasks according to cognitive process of inquiry in school. They are authentic inquiry, simple experiments, simple observations, and simple illustration. By following the cognitive processes given by the frameworks there are generating research questions, designing studies, explaining results, developing theories, and studying research reports. The inquiry ranges can be varied from authentic to simple illustration.

By the guidance of the frame, the findings of this study can be interpreted. First 39 reports in this study indicated that students generate their own test questions. It is a typical feature found in authentic inquiry.

In designing studies, most students used the given devices and materials by their own test designs including controlling variables, planning measures as well as selecting variables. At least 28 students who tried to find patterns and inference searching clearly indicated that they invented their own procedures of testing their questions rather than following the directions. It is a feature of authentic inquiry, too.

In the stage of explaining results, a half of them transformed their data into other forms including tables and figures. the other half failed to transform the data into other data formats. 29 of them tried to relate their observations to their test questions and find some patterns among data. However they even tended to straightforwardly relate their observation to the variables of interest. It leaded them to generalize only to exactly similar situations. These features correspond to between simple observations and simple experiments.

Unfortunately there were no finding on developing theories of authentic inquiry and studying research reports among 39 lab reports. Most of reports indicated that students tried to uncover empirical regularities, not theoretical mechanisms. Also they conducted a single experiment for their own test questions. There were few evidence to show that results from different studies may be partially conflicting, which requires use of strategies to resolve inconsistencies. No single student did read research reports either. These indicated that students were in the type of simple experiments.

Comparing with nature of exploration, and level of process found in this study, there were lots of common features found in the above description of cognitive process by Chinn and Malhotra (2002). The most frequent features of inquiry in terms of nature of exploration and level of process in this study were respectively inference searching and pattern identification. These features were similar to simple experiments except test questions created by students.

Discussion and Implications

Whether a full spectrum of authentic inquiry is feasible in school science classes may be hardly answered. However teaching approaches for adapting segments of scientific inquiry can be used referring to Inquiry guide of NSES (NRC, 2000). This study found that pre-service teachers experienced some features of scientific inquiry with elementary school science activity materials by using SWH. The analyses of cognitive processes shown in this study indicated that they were at least not in the level of simple illustration and simple observations. Rather they were one step closer to authentic inquiry. Interestingly, there were no consistency of their cognitive process found in their lab. reports. For instance, features of authentic inquiries and simple experiments presented concurrently. Students, who reveal some characters of authentic inquiry in their practice, may show lower level of cognitive process such as simple observations than authentic inquiry level. Back to the quotation of Inquiry guide of NSES (NRC, 2000), this finding is the good example of showing level of cognitive process and types of inquiry are sometimes unequivalent and incoherent. Still it is quite acceptable for school science.

This study illustrated also some distinctive cases to show cognitive process of scientific inquiry.: features of designing studies, transforming observation, reasoning to formulate explanations from evidence and planning procedures. Again this study showed segments of authentic inquiry rather than demonstrating its full sequences. Qualitative analyses with describing what happening in real classes collectively lead to further discussion on purposes and directions for improved school science inquiry in the future research.

Early back in 1926, Bobbitt (1926) described the importance of training students not only to reproduce facts but, more importantly, to develop the power to think in relation to the world's activities. Here 'the training' means scientific inquiry or scientific practice where students develop their knowledge about the nature of science. It will be more important for their teachers to have such training in order to train students in that way. Adapting the SWH template can be a good start to do so.

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