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How differently elementary students and undergraduates of elementary teacher education university coordinate experiment evidence and theory

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ABSTRACT

This study aims to explore how differently elementary students and their future teachers, pre-service elementary teachers dealt with evidence and theory by analyzing their journal entries for a science inquiry activity. Pre-service teachers took a science inquiry course and worked with self-directed inquiry by using Korean science elementary textbook. After inquiry activities, they provided science journals including their test question, data and claims on their inquiry. At the same time, elementary 4th grade students worked on science inquiry during their class with the same topics of the pre-service teachers. The collected science journals with three topics from both pre-service teachers and 4th graders were analyzed for the study. The journals of 79 from pre-service teachers and 54 from elementary students were compared in terms of quality of question and usage of evidence as well as characterizing types of coordination between evidence and theory. It was followed by discussion regarding the direction of pre-service teacher education of teaching science in elementary school as well.

Keywords: science journal, coordination of evidence and theory, elementary science inquiry

INTRODUCTION

How to teach science in elementary class is an on-going issue for science educators. Current reform efforts in science education focus on making meaning from everyday experience of students in terms of interaction with teachers (Scott & Mortimer, 2003). Children inherently draw upon the knowledge gained through everyday experiences with the natural world to reason about scientific phenomena during formal learning experiences (Hammer & van Zee, 2006).

Thus, teachers might be responsive to children's everyday thinking because children's ideas contain pieces of knowledge that are productive for science learning. It can be assumed that elementary teachers, like children, naturally construct ideas and thinking about scientific phenomena through their everyday experiences and interactions with the world around them (Murphy et al., 2017).

Pre-service teachers and 4th graders in this study were compared in terms of major element of scientific inquiry, which called coordination between evident and claim. Teaching science in elementary class would be an on-going issue in science teacher education. Coordinating between evidence from the experiment and explanation is one of the critical elements in scientific inquiry. The explanation can be theory at the end of scientific practice. In a science class, students would work just like scientists throughout the scientific inquiry activities.

Even in elementary inquiry, students can work with data and form their explanations. Students evaluate the evidence gained from their observation and coordinate the evidence with their explanation or theory that they have learned. Such a procedure of coordination between evidence and theory allows students to improve students' ability to construct their own concepts (Havdala & Ashkenazi, 2007).

Kuhn et al. (1988) stated that a core of scientific thinking would be forming inference through coordinating evidence and theory. The procedure, however, is not easy to follow. Students easily fail in differentiating evidence from theory (Kuhn, 2004). Students tended to count the observational evidence not using evidence-based evaluation but using idea-based evaluation (Park et al., 1993).

This study tries to explore patterns of coordination between pieces of evidence and theories by analyzing elementary students' and pre-service elementary teachers' journals for their science inquiry activities.

Table 1. Types of coordination

Type	Definition
Type 1	Consistency of evidence and theory/confirm what they have already known
Type 2	Consistency of evidence and theory/extension or elaboration of theory or claim
Type 3	Inconsistency of evidence and theory/do not change their knowledge by ignoring inconsistent evidence
Type 4	Inconsistency of evidence and theory/modify their claim counting on the inconsistent evidence

Scientific Inquiry

In science education, characteristics and features of school scientific inquiry have been searched and explored in many ways by researchers. At the international symposium (Abd-El-Khalick et al., 2004), researchers in science education made a list of processes for describing science inquiry (Grandy & 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, 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 and refining theories/models, writing about data, writing about theories/models, reading about data, and reading about theories/models.

This list interestingly included cognitive, social, and epistemological elements (Grandy & Duschl, 2007). For instance, writing about scientific theory is a cognitive task and at the same time it can ask students to do societal judgment (Norris & Phillips, 2008). It is because writing means that student authors need to possess delicate beliefs about the cognitive tasks of readers and at the same time ask students to do societal judgments. As students are making predictions, recording data, and organizing data, they may not concentrate on the writings. Therefore, writing tasks need to require different points of view and the epistemological judgment and reasoning of students. In summary, judgment and reasoning should be included in school science connected to the real world. Whether authentic inquiry is feasible in school science classes is a question that is hardly answered. However, as explained in "Inquiry and the national science education standards: A guide for teaching and learning" (National Research Council [NRC], 2000), teaching approaches and instructional features in scientific inquiry can be varied.

What experiences are provided for learners through inquiry occur in school science? Grandy and Duschl (2007) presented a list similar to the above but focused on what learners should learn in school science inquiry. It involved with learners' being engaged with scientifically oriented questions, giving priority to evidence, formulating explanations, and communicating and justifying their proposed explanations.

Coordination of Scientific Claims and Evidence

Some other times students have hands-on activity, but they have hardly any their own questions. Rather they are following the direction in so-called cookbook style experiment and try to find the one right answer and fill it out blanks in the activity workbooks. Teachers presented scientific facts to the class and students listened. Surprisingly this picture is working still at our current classroom in the 21st century (Schwab, 2016; Shin, 2018, 2019).

Existing constructivists are now moving toward post-constructivism. They started reforming with the first features, which they kept developing student-centered activities with a hope of earning the second goals of getting rid of student prior knowledge and catching the scientific concepts. The science education researchers, however, have found that such students' prior knowledge or alternative concepts are hardly removed and resilient to change. It made the researchers have more focus on the second features of constructivism. The science researchers develop new insights and to address questions including 'why are alternative conceptions resilient to change via instruction?' and 'why are some science topics more demanding than others to learn and to teach?'. The work involves a substantial shift in focus away from studies of students' alternative conceptions, and towards the ways in which meanings are developed through language in a science classroom. It is why post-constructivism is deeply weaved with classroom talks and students' making meaning (Shin, 2018). Authentic inquiry would be the venue for it and major component of such inquiry would be scientific argument and claims.

In the former research of Lee et al. (2012) with pre-service elementary teachers, four different types of coordination of evidence and theory were found. According to this research, there were type 1-consistency of evidence and theory, type 2-consistency of evidence and theory, including more extension or elaboration of theory, type 3-inconsistence of evidence, and type 4-inconsistence of evidence and theory followed by coordinating these types. This categorizing frame was adopted in this study. The types of coordination are summarized in **Table 1**. Type 0 was added to code the meaningless or unscientific claims found in students' journals. The journals of both pre-service teachers and elementary students were analyzed with the framework and compared to in terms of how both group worked on coordination of evidence and claims.

METHOD

Research Setting

The scientific claims were collected from the science journals that were implemented by 21 of 4th grade students and 29 of pre-service teachers. The science journals of 54 from students and 79 from pre-service teachers were collected as well. The class for both groups implemented science inquiry activity on three different topics in the following sequence.

1. **Stage 1.** Group of students worked on making test questions for comparing more effective thermos by using glass bottles, cotton, and aluminum foil.
2. **Stage 2.** Inquiry practice with group investigation.

Table 2. Topics of inquiry classes & number of collected journals from 4th graders & pre-service teachers

Topic		Number of collected journals
Topic 1	Measuring weight by beam balance	14 (4th grade students)
		29 (pre-service teachers)
Topic 2	Changes when water boils	19 (4th grade students)
		23 (pre-service teachers)
Topic 3	Heat transfer in solid material	21 (4th grade students)
		27 (pre-service teachers)

Table 3. Analytical framework for quality of questions (QQ)

QQ level	Definition
Level 1	Il-structured question Questions are not testable Unimportant & poor question
Level 2	Testable or maybe difficult to test May be meaningful questions Independent & dependent variables are not defined clearly
Level 3	Structured question Testable question Meaningful/essential question

Table 4. Analytical framework for justification of claims with evidence (JCE)

JCE level	Definition
Level 1	Claims without evidence
Level 2	Claims only with favorable evidence
Level 3	Claims with both favorable & insupportable evidence

3. **Stage 3.** Discussion and writing their own scientific journals at the end of the investigation.

All these topics were found in elementary science textbooks. The classes provided the worksheet for guiding students' science journals. It includes what students already know related to the topic, group inquiry question, experiment plan of independent, dependent, and controlled variables, measuring plan and observation, claims and evidence, and reflection of class. **Table 2** shows topics of inquiry classes and number of collected journals from 4th graders and pre-service teachers.

Research Procedures

Collected journals were analyzed in three ways. Firstly they were evaluated in terms of quality of the questions first. **Table 3** describes the analytical framework for evaluating the quality of questions in student science journals. The quality of questions will be evaluated with the following criteria:

1. Are they structured-questions?
2. Are the questions testable?
3. Are they answerable after carrying out an experiment?

Secondly journals were assessed in terms of justification of claims with evidence. **Table 4** describes the framework for evaluating how students use favorable and insupportable evidences in their claim making.

Lastly, types of coordination between evidence and theory were analyzed with a rubric of **Table 5**. It ranges from type 0 including meaningless statement and to type 4 with manipulating inconsistent evidential observation. In many low level of science experiment, students tried to observe what they expect or know from previous classes. For example, students learn that liquid water boils at 100 °C. When they work with boiling water experiment, most people found that water boils at lower temperature than 100 °C. Most students report their observation with 100 °C as boiling point. They ignore inconsistent observation after all. The desirable types of evidence and theory would be stating what they observe whether or not it is identical to what they know. And they modify or explain what they observe comparing with their theory or beginning understanding. CET type 1 and type 2 are dealing with consistent observation with their theory and 3 and 4 are inconsistent observation.

Table 5. Rubrics of coding types of coordination of evidence & theory (CET)

CET type	Definition
Type 0	Students' claims & evidence that are unrelated to topic Meaningless and/or unscientific statement
Type 1	Consistency of students' stating evidence & their claims Confirm what they already know Match what they predicted on their knowledge & observation
Type 2	Consistency of students' stating evidence & their claims Extension or elaboration of their claim
Type 3	Inconsistency of students' stating evidence & their claims Do not change their knowledge by ignoring inconsistent observation
Type 4	Inconsistency of students' stating evidence & their claims Modify their claim counting on inconsistent evidential observation

Table 6. Results of analytical framework for quality of questions from pre-servcie teachers & elementary students

Description of QQ level		Pre-service teachers 4th graders
Level 1	Il-structured question Questions are not testable Unimportant & poor question	56/79 (70.9%)
	Testable or maybe difficult to test May be meaningful questions Independent & dependent variables are not defined clearly	43/54 (80.0%)
Level 2	Structured question Testable question Meaningful/essential question	20/79 (25.3%)
	Il-structured question Questions are not testable Unimportant & poor question	10/54 (18.0%)
Level 3	Testable or maybe difficult to test May be meaningful questions	3/79 (3.8%)
	Independent & dependent variables are not defined clearly	1/54 (2.0%)

RESULTS

Quality of Questions for Inquiry

Table 6 described results of the analytical framework for evaluating the quality of questions in both elementary students and undergraduate students' science journals. In total, both 4th grade students and undergraduates showed QQ level 1.

Table 7. Results of analytical framework for justification of claims with evidence from pre-service teachers & elementary students

Description of JCE level		Pre-service teachers 4th graders
Level 1	Claims without evidence	8/79 (22%)
		21/54 (38%)
Level 2	Claims only with favorable evidence	16/79 (44%)
		30/54 (55%)
Level 3	Claims with both favorable & insupportable evidence	12/79 (34%)
		3/54 (7%)

Most of participants' questions were not structured and hardly testable as well as poor questions for scientific inquiry. 'QQ level 1' means failing in providing testable question. In this category there were 80% of elementary students and 71% pre-service teachers. In order to make structured question, clearly dependent and independent variables need to be verified. In other words, 80% of 4th graders do not know how to write testable question or structured questions. Nor do 71% of undergraduate students. For scientific claims, the most important work is making structured questions. In Korean elementary school science, how to make testable questions with dependent and independent variables have been hardly taught. For sure, these subject participants might not learn those. Yet in teacher education programs, pre-service teachers need to work on how to make quality questions for scientific inquiry.

Justification of Claims with Evidence

Elementary students showed different results from pre-service teachers. During experiments, only favorable data will not be obtained. There must be some favorable as well as insupportable data. In case of boiling water inquiry, most frequent insupportable data from experiment was boiling point. Most groups ended up with the temperature under 100℃ when water boiled. Such unexpected and insupportable data occurred because the condition of the experiment did not fit the ideal situation of boiling water including air pressure, water, utensil and so on. When their hypothesis was 100 ℃ of water boiling point. Some of students wrote that they would heat the beaker of water until the temperature reaches 100 ℃ instead of boiling water. Most of students failed in reading 100 ℃ but observed water boils in certain temperature, for example 93 ℃ or 97 ℃. It brought out such insupportable data. 34% of pre-service teachers stated such insupportable data as evidence and made their own claims (JCE level 3 in **Table 7**).

However, only 7% of elementary students used insupportable data as evidence for their claims. 38% of elementary students and 22% of pre-service teachers failed in reporting evidence for their claims. And 55% of elementary students and 44% of pre-service teachers only used favorable data as their evidence. They dropped the insupportable data when reporting their claims. In summary, pre-service teachers were a little better in justification of claims with evidence.

Types of Coordination of Evidence & Claims Found in Elementary Students' Journals

In terms of three topics for scientific inquiry for the study, I found several common features for both elementary and undergraduates students' journals. Regarding topic 1 of measuring weight by beam balance, most students clearly linked their knowledge and their observation during the experiment. In this activity, students simply checked what they know regarding the activity. Therefore, hardly any student struggled with unexpected data, and they worked toward modifying their claims. CET type 1 was most frequently seen in this topic. For instance, student A claimed to make balance even with using different weight balances, such as 70 g and 20 g. It means that the student understood beam balance and the inquiry activity confirmed it.

In case of topic 2 of 'changes when water boils', CET type 1 was the most frequent. Students started the test or inquiry with the right understanding of features of boiling water. They only checked what they already know through the test. For example, student G already had the knowledge that boiling water changes liquid water into gas, which is vapor. He tried to test how much water would reduce during boiling. He predicted that the water volume will be decreased after boiling. He only confirmed what he knew after the test.

Regarding topic 3 of 'heat transfer in solid material', CET type 1 was most frequent, while CET type 4 was also found. Student P predicted that when applying heat to candle paraffin, the melted paraffin would remain white in color. However, she observed that the melted paraffin changed into a transparent liquid, and she modified her claims, which was different from her beginning understanding based on the evidence.

Types of coordination of evidence and claims found in science journals of 4th graders and undergraduate students presented in **Table 8** and **Table 9**. The most frequent type for elementary students was CET type 1 in **Table 8**, which means that elementary students predicted before the test based on their learning and confirmed it with the observation from the test. However, it was hardly found that students reconstructed their knowledge after the test.

However, pre-service teachers showed a little different result. Yet the most frequent CET type was CET type 1 as elementary students did. While elementary students with CET type 1 was 81%, pre-service teachers 44%. Pre-service teachers showed CET type 3 with 25%. CET type 3 indicated inconsistency of students' stating evidence and their claims. While they found inconsistent observation with their beginning understanding, they just ignored inconsistent observation and did not change their knowledge or beginning understanding.

It can be interpreted that theory in the inquiry questions was frequently understood by pre-service teachers, and they selected supporting evidence that was found using the data available to them. The significant relations between activity topics and frequencies of coordination types were rarely seen. The findings in this study might explain how they robustly keep their previous knowledge with experiment planning, data analysis, and interpretation and make their own scientific claims. CET type 1 and type 3 are similar in some points that previously possessed knowledge is resilient even with or without insupportable evidence. In the previous research with pre-service teachers (Lee et al., 2012), the most frequent type was CET type 1. The result was similar to this study.

Table 8. Summary of types of coordination of evidence & theory (CET) found in elementary student journals

Topic	CET type 0	CET type 1	CET type 2	CET type 3	CET type 4	Total
Topic 1	0	14	0	0	0	14
Topic 2	1	18	0	0	0	19
Topic 3	4	12	1	1	3	21
Total	5	44	1	1	3	54
Percentage (%)	9	81	2	2	6	100

Table 9. Summary of types of coordination of evidence & theory (CET) found in elementary pre-service teachers journals

Topic	CET type 0	CET type 1	CET type 2	CET type 3	CET type 4	Total
Topic 1	4	2	0	14	3	23
Topic 2	5	19	4	0	1	29
Topic 3	5	14	2	6	0	27
Total	14	35	6	20	4	79
Percentage (%)	18	44	8	25	5	100

If it led to the interpretation of that teacher's epistemic knowledge was transferred to their students, it will be going too far. However, this is still a possible idea for teacher training. The pre-service teacher education should focus on the finding of this study, which is the coordination of students' observational evidence and their claims during the scientific inquiry. Their understanding of such coordination may help them while conducting classes with elementary students. In summary, the findings in this study connect to the point of how students collaborate their previously owned knowledge with experiment planning, data analysis, and interpretation and make their own scientific claims.

CONCLUSIONS

This study found that elementary students and their future teachers showed similar patter in dealing with coordinating evidence and theory during scientific inquiry. Both failed in properly recognizing evidence among data from scientific inquiry and having opportunities of experiencing scientific knowledge out of inquiry practice. For both, data and observation from scientific inquiry are not related to their own claim making or meaning making. In short, they do not even try to coordinate what they already know and what they observe in their experiment. The similar disappointing results from both pre-service teachers and elementary students will lead us to predict no improvement of such situation in future school.

Theoretical discussions about science education and democratic participation in science and technology (e.g., Levinson, 2010; Yacoubian & Bazzul, 2015) have brought issues of agency, activism, social justice, engagement, and participation to understandings of what it means to be a scientifically literate citizen (Pedretti & Iannini, 2020). More attention goes to the emergence of what we identify as progressive views of scientific literacy. Such movement is based on scientific practice in school science not only with infusing more experiment and activities, but also with participating in authentic process of making meaning including coordination of theory and evidence. Based on this study, our elementary students and even their future teachers are similar in perspective of scientific meaning making with their inquiry process.

Students' attitude towards science and their learning goals in science are strongly influenced by teacher-student interactions and by teachers' own expectations and attitudes (Hattie, 2009; Osborne et al., 2003). Of course, how to make knowledge of science would in the same wavelength. Unfortunately, primary teachers are often influenced by negative experience with science during their own primary and secondary school education, which often results in negative attitudes towards science that persist even after their pre-service teacher training (Jarrett, 1999; Mulholland & Wallace, 1996; Palmer, 2002; Sanger, 2008). Such negative attitudes may manifest themselves in lower levels of confidence and self-efficacy beliefs about teaching science, in devoting less time to teaching science in the classroom and in increases in teachers' self reported feeling of dependency on standarised instructional methods (Goodrum et al., 2001).

Promoting a positive attitude towards teaching science among primary teachers is therefore critical when aiming to foster primary school children's positive attitudes towards science (van Aalderen-Smeets et al., 2017). Most primary teachers find it even more difficult to teach scientific practices in the form of inquiry-based science, as they lack sufficient familiarity with the process of scientific research itself (Smith & Anderson, 1999; Yager, 1997). This is the case even though it has been well established that science education should not only address content knowledge but should also be taught as the process of science. This means advocating teaching and learning by inquiry and adopting an inquisitive habit of mind, in order to foster students' positive attitudes towards and engagement with science (Osborne, 2014). Inquiry learning is a constructivist practice that supports meaningful learning (van Aalderen-Smeets et al., 2017). It refers to the inquiry process as a way to learn and obtain knowledge. The critical element of such a process is coordination of evidence and knowledge that students possess in the name of theory. As shown in this study, neither of elementary students nor pre-service teachers succeeded in fulfillment of scientific inquiry practice. The definition of inquiry learning implies that teaching science through inquiry does not necessarily require a fully complete and delimited science lesson. It can be integrated within the curriculum as a whole, even through small activities such as asking different types of questions to stimulate children's curiosity.

Therefore, encouraging inquiry practices in primary schools calls for teachers to become familiar to some degree with the process of conducting inquiry projects. The teacher training program even for elementary school should provide such experiences for future teachers in terms of curriculum of science teaching methods and science projects.

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