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Analyzing Science Teachers' Understandings about Scientific Argumentation in terms of Scientific Inquiry

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Abstract: The purpose of this study was to investigate science teachers' understandings about scientific argumentation in the classroom. Seven structured interview protocols were developed, asking the definition of scientific inquiry, the differentiation between scientific inquiry and hands-on activity, the opportunity of student argumentation, explicit teaching strategies for scientific argumentation, the critical example of argumentation, the criteria of successful argumentation, and the barrier of developing argumentation. The results indicate that there are differences and similarities in understandings about scientific argumentation between two groups of middle school teachers and upper elementary. Basically, teachers at middle school define scientific inquiry as the opportunity of practicing reasoning skills through argumentation, while teachers at upper elementary define it as the more opportunities of practicing procedural skills through experiments rather than of developing argumentation. Teachers in both groups have implemented a teaching strategy called "Claim-Evidence Approach," for the purpose of providing students with more opportunities to develop arguments. Students' misconception, limited scientific knowledge and perception about inquiry as a cycle without the opportunity of using reasoning skills were considered as barriers for implementing authentic scientific inquiry in the classroom.

Key words: scientific argumentation, scientific inquiry, reasoning skills, procedural skills, claim-evidence approach

I. Introduction

Scientific inquiry in K-12 classrooms tends to be procedural and lacks opportunities for students to understand how scientific knowledge is constructed through reflection, debate, and argument (Gallagher & Tobin, 1987). Furthermore, limited opportunity to develop scientific argumentation skills prevents students from practicing scientific thinking skills needed to understand the nature of scientific knowledge and the role of scientific inquiry. Science education reformers argue that scientific literacy has become a necessity, stating that everyone uses scientific information to make choices that arise daily (Flick & Lederman, 2006). For this purpose, the *National Science Education Standards* (National Research Council [NRC], 1996; 2000) present a vision of a scientifically literate populace by outlining what students need to know, understand and be able to do by understanding what scientists do to construct new knowledge through scientific inquiry. Consequently, recent research has focused on supporting opportunities for students to learn scientific argumentation in the context of scientific inquiry (Osborne, Erduran, & Simon, 2004; Lawson, 2005).

Studies about scientific inquiry emphasize that students need to learn how to think scientifically through their argumentation, enabling pupils to differentiate between evidence and theory, while coordinating the two in order to understand how scientific knowledge is constructed (Kuhn, 1993; Kuhn, 2007). Kuhn (1993, 2007) implies that educators need to develop lessons which provide students with argumentation opportunities. In this point, it is essential to investigate how much teachers understand about scientific argumentation as well as the problems that students can experience, so that they can generate a variety of prompts and questions designed to stimulate students' thinking in appropriate directions, while directing students away from misconceptions (Pressley, Hogan, Wharton-McDonald, Mistretta, & Ettenberger, 1996). Therefore, this study aims to gain insight into teachers' general understandings of scientific argumentation in the classroom and then use

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these findings to suggest opportunities for implementing further study. This study consists of the following research questions: (1) What were science teachers' knowledge/understandings about scientific argumentation in terms of scientific inquiry? (2) What kind of explicit teaching strategies did they use for the opportunity of scientific argumentation?

Ⅱ. Theoretical Underpinning

Scientific inquiry is one of ways that scientists build new scientific knowledge (NRC, 1996; 2000). Reformers in *Standards* (2000) recommend that students need to have opportunities to experience scientific inquiry in order to understand how scientists construct new knowledge. During the inquiry process, students are supposed to develop understanding of how they know what they know and what evidence supports what they know. Many studies, however, have found that scientific inquiry practices implemented in the classroom require only low cognitive thinking processes or are just "cookbook" type activities which lack opportunities for students to truly understand and explore the nature and limitations of scientific knowledge building (Gallagher & Tobin, 1987; Krajcik *et al.,* 1998). Gallagher & Tobin (1987) revealed that teaching scientific inquiry currently focuses more on hands-on activities than on reasoning about the process and results. Krajcik et al. (1998) implied that getting students to understand science as inquiry requires the intellectually stimulating activities of argumentation and communication as well as hands-on activities such as experimentation and exploration.

Driver, Newton, & Osborne (2000) state that argumentation is important within the social practice of science because students need to develop knowledge and understand the evaluative criteria used to establish scientific theories, which in turn will further the public understanding of science and therefore improve scientific literacy. It is also implied that a pivotal teaching strategy for teachers to provide students with the opportunity for argumentation is using small group activities with peers or teachers (Driver, Newton, & Osborne, 2000; Oliveira, & Sadler, 2007).

Students are supposed to express and promote the *scientific thinking skills* needed to understand the nature of scientific knowledge (Osborne, Erduran, & Simon, 2004). Kuhn, Amsel, & O'Loughlin (1988) claimed that the heart of *scientific thinking* is the ability to differentiate between evidence and theory and to coordinate these two appropriately to construct new knowledge (Kuhn, 2007). *The process of scientific thinking* to revise those models or theories between child and scientist is different (Dunbar & Klahr, 1989). Students can develop and promote scientific thinking skills by developing argumentation through teachers' questions and prompts.

Therefore, it is necessary for teachers to provide students with opportunities for practicing argumentation. Before investigating what kind of teaching strategies are most effective, however, it is important to examine how teachers understand scientific argumentation first. Teaching practices in the classroom are viewed and organized through the lens of teachers' understandings, which is defined as beliefs (Hollingsworth, 1989; Kagan, 1992). Teachers are an essential factor in determining what they plan and how they teach (Richardson, 1996). Therefore, in this study, it is essential to develop profiles teachers' understandings about scientific argumentation in term of scientific inquiry before further investigating teaching strategies. Teachers' understandings about science teaching influence their perceptions and judgments which affect their classroom practices (Southerland, Gess-Newsome, & Johnston, 2003; Pajares, 1992). When teachers' understandings influence the practice of teaching, it is necessary to investigate how much teachers sufficiently understand scientific argumentation in order to implement ideal explicit teaching strategies for students' argumentation (Roehrig & Luft, 2001; Maor & Taylor, 1995; Mackenzie, 2001).

Secondary science teachers' understandings about scientific argumentation in terms of scientific inquiry were explored through semi-structured interviews in this study. The term of "secondary" indicates the level of 5th and higher in the state: this categorization system is the reason why upper elementary teachers (teaching 5th graders) and middle school teachers were selected as targets for this study. Out of nine secondary teachers, one teacher was then selected for further investigation of teaching practices to see how he provided students with the opportunities of argumentation on the basis of his understandings. The practices displayed by one teacher were described qualitatively based on ten hours of classroom observations each from two different blocks of classrooms.

Ⅲ. Methodology

1. Data Collection

For this study, it was important to select science teachers who are really interested in implementing scientific argumentation for students learning science as inquiry. For this purpose, nine science teachers had been contacted by purposive sampling method. I, as a researcher of this study, have worked with science teachers through workshops, conference, and projects for years; therefore, these experiences with science teachers and other science educators in the department were used in selecting exemplary science teachers in the range from 5th and 8th graders (which is called 'secondary' level, covering the level of 5th and higher) who were interested in developing their lesson modules in terms of scientific argumentation. Teachers from 5th to 8th grade level are those whose students are beginning to develop key abilities to do and understand about scientific inquiry (Carey, 1989). The teachers participating in this study are representative of science leaders in each county under the goals of teaching and learning science as inquiry and they have participated in "Scientific Inquiry Summer Workshop" for four years in a sequence supported by some educational institutes and science education department of universities in one of the states. Through inquiry professional development program, teachers had chances to learn science content and pedagogical skills to promote skills of teaching and learning science as inquiry. Once selected teachers signed up to participate in the study, I interviewed them with protocols (Appendix 1), asking their knowledge and understanding of scientific argumentation. Regarding these interview protocols, I worked with science education expert to construct the content validity through discussion to see if those protocols were appropriate to capture teachers' knowledge about students' scientific argumentation and their explicit teaching strategies. All interviews were audio-taped to be transcribed later. After interviews, the selected nine teachers and I made another schedule for the class observation. These teachers were observed only once each to see how they provided students with opportunities to develop scientific argumentation. These participating teachers each selected one of their best lessons so that I could observe explicit teaching strategies, which provide students opportunities to develop scientific argumentation. Class observations focused on teachers' explicit teaching strategies to see how they scaffold students to develop their scientific argumentation, such as what kind of questions, hints or clues teachers used during their teaching. The teaching strategies employed by teachers were related to their knowledge about scientific argumentation to see in what ways they implemented opportunities of argumentation during the lesson. Observational protocols of OTOP (OCEPT-Teachers Observational Protocols; Appendix 2) were used in analyzing teachers' explicit teaching strategies. This instrument has ten items reflecting the envisioned teaching strategies by the science education reform (NRC, 1996), which includes using technology, using pedagogical content knowledge, checking students' prior knowledge and misconceptions, implementing inquiry teaching, and understanding habits of mind (Morrell, Flick, Park, Perkins, & *et al.,* 2003). Each item ranges from scale 0 (Not Observed) to 4 (Higher Frequency) to describe the patterns of teaching strategies embedded qualitatively. Fieldnotes were taken during observations. All nine teachers had over 16 years of teaching experience and they also possessed master degrees in education or science. Four were from upper elementary (teaching 5th grade) and the other five from middle school level (7th or 8th grade). Five were female and four male. Every teacher participated in professional development programs as many as six times annually. All teachers were members of at least three different professional associations nationally or internationally

Finally, the data from interviews and class observations guided me to select only one informative teacher for further investigation. I selected this teacher (Jim) based on nine teachers' interviews and practices of class observations collected. The criteria to select him included: (1) He had scored high (3 or 4) in most items of OTOP through the first class observation; (2) He had released certain and structured knowledge about scientific inquiry, scientific argumentation, and students' opportunity to develop their reasoning skills envisioned in the *Standards* (2000); (3) He had also displayed his explicit teaching strategies designed to implement for students' opportunities to develop their arguments, especially, *Claim-Evidence Approach* (CLEA); (4) He had regularly been attending professional development programs, such as workshop and conferences, to pursue for more and better developed pedagogical content knowledge related to scientific inquiry and argumentation. Jim was observed for ten hours in two different blocks of classrooms and he taught the same unit of Newton's law with two different blocks (two classrooms of 7^{th} graders; 3^{rd} block and 4^{th} block). During each class observation, I used observational protocols of OTOP (OCEPT-Teachers Observational Protocols) to see how Jim provided students with opportunities of scientific argumentation. I also took fieldnotes to describe the physical classroom context on the spot. CLEA, one of Jim's explicit teaching strategies, is described in this study, explaining how he provided students with opportunities of developing argumentation.

2. Data Analysis

To interpret the teachers' understandings about scientific argumentation, a coding system was employed based on the interview protocols after all interviews were transcribed. Certain categories were developed to each interview protocol and they were used to describe teachers' understandings about scientific argumentation as well as scientific inquiry at secondary level of science teachers.

To describe the finalized teaching patterns in the context of scientific argumentation, a composite was developed based on OTOP scores from ten hours of classroom observations. First, a table listing the teacher OTOP rating for each item from each observation was developed with the scores and evidence based on fieldnotes. Second, a line graph showing the sets of OTOP ratings for comparisons was also developed. Lastly, patterns and interpretations of the total data set (depending on observations), OTOP ratings and interview data were developed.

IV. Results

1. The Teachers' Understandings about Scientific Inquiry

The differences and commonalities are identified in defining scientific inquiry, differentiating inquiry activity from hands-on activity, and providing students with opportunities of developing argumentation in order to understand the nature of scientific inquiry. The different themes were recognized by Middle School Teachers (MSTs) and Upper Elementary School Teachers (UESTs) according to interview protocols needed to describe their understandings about scientific argumentation as well as inquiry.

(1) Definition of Scientific Inquiry

MSTs defined scientific inquiry as the holistic way, starting from framing inquiry questions to finding answers to these questions. The MSTs defined inquiries as involving three aspects: (1) the combination of procedural skills of developing questions, (2) designing the experimentation, and (3) pursuing answers through developing reasoning skills. At this point in the study, the MSTs stated that the opportunity of demonstrating students' reasoning skills is essential to do scientific inquiry. The phases of collecting, finding patterns, interpreting data, differentiating evidence from data, and using evidence to support each position were considered as an opportunity to demonstrate reasoning skills cognitively.

> I think it has to do with providing a question to focus the kids, to get them headed in a certain direction, giving them a very open-ended question to when they can then find a variety of ways to get at answering their question, that is, finding evidence by using scientific processes, setting up a lab, designing a lab, collecting the data, and then displaying it. I have found some evidence to support my answer (MST, Jeff)

> It is where the kids have noticed something that they want to find scientific evidence for. They are investigating first hand what is going on (UEST, Mary)

> We have been trying to work more this year on interpreting data. That has been a real big focus and trying to get [omitted] How happy are we with this data? How tight is the data? What is weird about this data? Does this data answer our question? We have tried to focus on once we have collected the data, now what can we figure out from it. That has been interesting (MST, Angie)

All of the interviews transcribed above indicate that the MSTs define scientific inquiry as the opportunity of differentiating evidence from data to support a student's hypothesis or question. However, the MSTs also reveal that it is hard to let students learn how to differentiate evidence from data which can be used to support their positions logically.

> Very seldom does one student say one thing and another student says another thing, and they defend their arguments. Typically in a class, many people will answer the same way and they may have different evidence for answering the same way. There is not very much of students arguing with each other. It is more in relationship to the question, what data is there to support it or not (MST, Angie).

Angie, one of the MSTs, states that there is little opportunity for students to develop argumentation during scientific inquiry.

On the other hand, the UESTs define scientific inquiry as the opportunity to develop procedural skills through physical experience in the context of highly structured inquiry activities. More than this, students need to have a chance to participate in procedural skills, such as developing questions, collecting data, and transferring that data with the use of bar or pie graph. The UESTs believe that it is more important for students at elementary level to learn procedural skills first in each phase of the inquiry process.

> It might be their first experience with that specific question [omitted] It is focused on one question. In my class, with my students, it is very highly structured. It is not the time when they are exploring and observing and they are not – how do I want to put this – it is not a free exploration time at all. It is a time for them to answer a specific question [omitted]. Together we set up the procedures. We know exactly how they are going to test it, and how the variables will be controlled. When they go through the procedure that we have designed and they record what happens when they are going through that procedure (UEST, Becky).

> The way I have brought it up to them is at a very basic rudimentary level (MST, Mike)

> I always think if I have science content to get across to my kids, but I also have a process of science inquiry going. So I try not to mix them at first, when it is brand new to them, because the inquiry at fourth grade, I think is a process that they need to learn [omitted] I like to use it as a process that the kids learn, because they are tested on it. I teach that separately from content [omitted] Right, because I think if I put it together the kids are real confused. That is why I keep it, at this level, separate (UEST, Sherry)

In addition, some of the UESTs responded that students learn the basics of scientific inquiry when the teacher provided the opportunity explicitly.

> We do discuss about the nature of science and how scientists use that process to find out answers to questions. Lot of times I'll tell the kids (UEST, Sherry).

> My goal is to let them know that it is okay to be curious, and if I can help them find out, I will. They are afraid to be wrong (UEST, Sue).

Here, Sherry and Sue agreed that students should have opportunities to make errors and be curious to conduct scientific inquiries.

Overall, scientific inquiry is defined as the opportunity of demonstrating reasoning skills through developing argumentation by the MSTs, and as the opportunity of practicing procedural skills through physical experience of experimentation by the UESTs, which is sometimes separated from the science content.

(2) Difference between scientific inquiry and hands-on activity

The MSTs believe that scientific inquiry is the combination of hands-on activity and reasoning skills through communication or connection between hands-on activity and science content from the textbooks. For example, one of the MSTs responded that scientific inquiry is the chance for students to think critically by demonstrating that they form explanations with evidences collected from experiments. Students could understand the nature of scientific knowledge through the process of supporting their hypothesis or refuting others by data from experimentation, which is called “Argumentation.”

> I think you can do scientific inquiry with a demonstration. I think it is all about students thinking critically and looking at, making observations, and then trying to interpret, analyze what they see, and then hanging that on what they already know and then coming up with some logical explanation or something to support what they see. [Omitted] They are going to have ownership if they have hands-on. (MST, Jeff)

> They have to state their evidence right there based on their background and information. Then I require, in their analysis, for them to go back and read the claim, read their evidence and then state whether or not if they have learned anything from the beginning of the investigation to the end. Do they still think that evidence is valid? Do they still think that claim is valid, and why? The “and why” part is where they will pull in their collection of data to prove or disprove what is going on. (MST, Jim).

The UESTs also responded that hands-on activity comes first as exploration but scientific inquiry comes later as the opportunity of thinking skills at the end of the inquiry process. Some of the UESTs displayed that students seem to just play through hands-on activity, but communicate through scientific inquiry.

> Their freedom to explore comes before we start designing scientific inquiry. [Omitted] if I want to do an inquiry that is focused around magnets, they are going to have to have a chance to experience magnets and try different materials with them, and find out that they will attract through paper and that one magnet can repel another. They will get a chance to explore and play with them before we ever start structuring a scientific inquiry, before I have even given them background information (UEST, Becky).

> We will talk about the science, what is happening, why it is happening, what could be done to change it or improve it. So there is more structure to it than just playing around [Omitted] there is an attempt to get at the science behind. What is it that they are doing? (UEST, Mike).

Overall, both the MSTs and UESTs understand scientific inquiry as the opportunity to develop reasoning skills through argumentation or communication. However, the differences in ideas about scientific inquiry are that procedural and reasoning skills take place together according to the MSTs, whereas the procedural skills come first and reasoning skills comes later in the latter phase of inquiry activities as described by the UESTs.

(3) How students demonstrate their reasoning skills

The MSTs responded that students can demonstrate their reasoning skills when they have chances to use their own collected evidence from experimentation to support their claims, which allows them to form explanations. In addition, students have an opportunity to discuss why they cannot get the proper supportive evidence from experimentation, which means they have a chance to carry out another experiment, enabling them to collect or replicate further data to support or oppose their own evidence rather than provide fake or insufficient data.

> You claim this, so show me evidence (MST, Jeff).

> Usually, with the old way that we used to teach science where they made a hypothesis, they did their experiments, if it didn’t come out right, they would fudge their data to make it support their hypothesis or they would change the hypothesis to fit their data. This way they don’t seem to feel as big need to do that. They will say, no, it didn’t work out the way I thought, but these are the reasons it doesn’t work. To them it seems to feel like it is still validating their process, even though their hypothesis was wrong (UEST, Mary).

On the other hand, the UESTs believe that students can demonstrate their reasoning skills when they are able to apply their knowledge into new context for the prediction, to frame and develop the questions by themselves, to demonstrate their communication skill about the results to the other peers or teachers, and to understand the goals and questions of activities in the classroom.

> In terms of teaching strategies what I think is really crucial is that kids talk to each other. I think that is absolutely critical. [Omitted] But I also really structure it because in spite of the fact that I firmly believe that they need to work in groups, I have to have order in my classroom (UEST, Becky).

> Now I can structure it as a question or a claim that someone wants to prove, and that defines what we are going to do in the investigation, rather than just providing a list of steps of things to go through. I have used that, and I felt that the kids have been able to better understand the process, much more than standing up there saying, "OK, what is your question? What is your hypothesis? What is your procedure?" It makes the activities and the vocabulary much more meaningful, much more real-life to them (UEST, Mike).

Overall, the participants in this study believe that reasoning skills can be proven through communication or argumentation in the social context. The MSTs define reasoning skill as a students' ability to develop a claim and to use the evidence supporting the claim, whereas the UESTs define it as a students' ability to develop communication depending on the teachers' engagement with guidance.

(4) Explicit teaching practices for scientific argumentation

Here are the common opinions from both of groups of teachers in this study about explicit teaching strategies for students' argumentation.

First, both groups believe that in the social context of community (such as group working or whole class discussion where students can compete with one another defending their own position) is pivotal for students to develop scientific argumentation. Furthermore, the explicitly assigned roles to students in groups (such as data recorder, questioner, or analyst) help them develop argumentation.

> You can do a small group and at the end you can group those people who had similar questions that they were answering and then they can share their evidence, they can share their conclusions within the group. You can certainly do it the old fashioned traditional way, you write it down. You communicate it through paper and pencil and then get feedback from the teacher. You can certainly do a whole class discussion. You can have students do some response to discussion. In other words, peer interaction, peer discussion. [Omitted]Debating things, what is your conclusion to your answer and why? This person says, "I can shoot some holes into that." (MST, Jeff).

Secondly, interdisciplinary connection (such as lab reports, writing journal, or reading discipline) is crucial so that students can logically express their opinions logic. Currently, teachers provide certain reflective assessment, such as inquiry guides, inquiry web or inquiry wheel rather than inquiry cycle. The inquiry cycle consists of continuous states of inquiry activities, whereas inquiry wheels or inquiry webs are cycles with questions at its center, so that students stop to have opportunities to reflect on each phase of the inquiry activity.

> The kids practice writing a title, purpose, procedures, results, conclusions. They get that pretty quickly. It is the conclusions; the argumentation is the tough part. Every year I have to remind myself I have to spend more time on this, how can I do this better. What I do is teach the kids, coming up with an argument, and it is called scaffolding. It is something like this. Write two or three sentences and focus on this, on your conclusions. It is like taking an argument and breaking it down into five parts. The kids may have the arguments in their head, but how do they get started. If I tell them, write two or three sentences on this part. So they write two or three sentences. Then write two or three sentences on the second part. What I am doing is I am focusing their attention on aspects of the argument or the conclusions (MST, Matt).

> I guess accuracy, because going back to the second dimension of materials and procedures, which they need to write exactly what they did down so that somebody else could do the same experiment exactly the same way. I don't know. On this reasoning, I'm not sure, because it is so much repetition. You do it over and over and over again, and pretty soon they are, "Oh, I know what I am supposed to do." It is a process, but the reasoning, I don't know, because I think on some things I could get them to believe differently. (UEST, Sherry).

Third, it is important for teachers to create an authentic inquiry environment through questions and guidance, where students can make mistakes, express their ideas freely, understand the nature of scientific inquiry and scientific knowledge by expressing their divergent thinking, and make decisions about the results.

> One of your main goals should be setting up an environment to where it is safe to express yourselves, save to clarify, safe to ask questions, where the kids suddenly feel that it is okay for me to ask a question that they consider a stupid question. Then if you can establish that tone in your classroom, then if you have a discussion period where they are trying to support their evidence, they don't feel shy about it. They are more open. They are more assertive. They feel more relaxed (MST, Jeff)

Finally, all teachers in this study learned and employed new instructional teaching, the *Claim-Evidence Approach* (CLEA), and implemented it for the purpose of developing argumentation, since it was designed to provide students with chances to practice supporting their claims or refuting others with evidence collected from experimentation. CLEA has two characteristics: a deductive approach and an evidence-based approach. Students are expected to develop their own claims based first on their reading texts, and then design investigation to collect, analyze and interpret data to develop results with their own supportive evidence from experimentation.

> Asking the kids to look at answer and then compare their own answer to the well supported one. We have been trying to give them opportunities to look at a variety, a continuum of supported answers and judge which is the best supported, judge which one is most like theirs, and then fix their to be well supported. We have been trying to build that in, maybe every fifth or sixth lab or something like that. Some of them lend themselves to it better than others [omitted] When you give them five or six different answers, put these in order of most supported to least supported, then they can start to do that. Our hope has been that by doing that every now and then, they, themselves, will start to internalize what a well supported answer is and start to write them themselves (MST, Angie).

> I have used the knowledge claim approach because it has a nice structure and kind of linear direction that they can follow. They have been able to create some investigations [Omitted]. For me it is a perfect extension of the cognitive strategy work I was doing, and it puts it all in a very structured way that is readily accessible to the students [Omitted] the cognitive strategies work that he and I were doing. I have started slowly to instruct on cognitive strategies, how to set a purpose, and what that is and how to get at prior knowledge and what kinds of prior knowledge we can bring to an investigation. Also, being aware of your thinking as you are working, the meta-cognitive piece. I am starting to try to teach them those different strategies in a lot of different areas, not just science, and the hope being that they can then apply that when becomes useful, as it frequently does in inquiry (UEST, Mike).

(5) Successful example of scientific argumentation

All teachers in this study believe that it is successful when students had a chance to use their evidence or knowledge to explain their findings through argumentation during CLEA. For example, students could demonstrate their abilities to develop claims, differentiate evidences from data, thereby supporting their claims, and forming explanations. Here are the examples of developing argumentation during CLEA.

> That magnet will stick to or attract metals. That was the claim, which leads to the question, "do magnets attract metals. From that the students, if they attract metals?" then they will stick to the metal. What we need to know is "do magnets stick to those metals. Given that framework, the kids were able to come up with some basic steps on how they would explore that. They would try magnets with lots of different metals to see if they attracted or not. They were able to come up with a simple little table, but to keep track of their observations. They were able to grab it. It is not a very sophisticated investigation, but they were able to carry out a simple investigation (UEST, Mike)

> We can go back to the whole friction thing where students were testing the effects of different surfaces on how far something would slide. By looking at how those distances changes, they were able to then look at the surfaces and try to draw some kind of correlation between what is this surface like compared to the other one, and why would that make a difference? Why would that change the amount of friction? Another example, the cup absorb testing I think has a lot of potential. We were testing

different kinds of cups to see which would be best to prevent heat transfer. Again, very simple tests, but then they need to look at the materials and analyze and look and inspect and make observations, and then from what they know about heat transfer, they need to then say the Styrofoam cup has more pockets or whatever. (MST, Jeff).

(6) Barriers for developing argumentation

These are the barriers which prevent students from developing argumentation as displayed by the MSTs; (1) factual rather than procedural knowledge, (2) understanding inquiry as separate pieces rather than the holistic way, (3) focus on procedural skills without cognitive chance, (4) undeveloped students' attitudes about science, (5) gender issue, and (6) undeveloped ability to employ interdisciplinary skills, such as math.

I just think they are not very used to thinking logically. They are kind of used to kind of saying what they think. You really have to train them and try to teach them that they have to support what they think with something. I think that is the biggest barrier (MST, Angie).

These are the barriers identified by the UESTs; (1) limited scientific knowledge, (2) low attitude about science, (3) understandings inquiry as a cycle rather then a wheel, (4) undeveloped communication skills, and (4) inquiry with the emphasis on procedural skills only.

Sometimes what they write doesn't really communicate what they know. Other times they don't have the vocabulary to describe relationships. They have the vocabulary to describe things, but not interactions and relationships (UEST, Sue).

No doubt about teachers' teaching as knowledge accumulation Fourth graders are very literal. They often don't think that I could be wrong. Some really enjoy proving me wrong. It is at a point where most kids pretty much believe anything you tell them. If I said, all metals attracted to magnets and this piece of tinfoil doesn't, it just kind of goes over their head (UEST, Sherry).

Undeveloped attitudes about science and inquiry activities with an emphasis only on procedural skills without demonstrating cognitive abilities are identified commonly by the MSTs and UESTs as the barriers preventing students from developing argumentation.

(7) Criteria for successful argumentation

The MSTs regard the use of new scientific terms by students in explaining the phenomenon as an indicator of successful argumentation, while the UESTs identify the students' abilities of developing new rising researchable questions as an indicator of successful argumentation.

They would have to be able to formulate a question that could be tested. That is a very important thing. Another big skill that we work on is after we have done an investigation, can they go back and in their mind's eye remember the steps that they went through and write them down in a way that another group could follow it (MST, Jim).

I talked to them; ask them what's going on, what is this mean. I may say "Explain to me what is going on there." That is one thing I've change over the years (MST, Matt).

2. Implementing Scientific Inquiry in the classroom

In this session, one of teachers participating in the study was selected for further investigation about his teaching practices. To date, the understandings about scientific argumentation as well as inquiry have been examined by interview and it has been concluded that all of the teachers possess a sufficient understanding about scientific inquiry as envisioned by the *Standards* (NRC, 1996; 2000). Jim, one of the MSTs in this study, was observed for ten hours in two different blocks of classrooms with the use of OTOP tools, describing the generalizable patterns of reform-based teaching envisioned by the Standards. Jim employed CLEA for the purpose of providing more chances of argumentation amongst his students on the subject of Newton's laws.

A structured observational protocol, OTOP, was employed for the purpose of describing the pattern of Jim's instruction. There are ten OTOP items describing effective teaching strategies envisioned by the *Standards* (NRC, 1996; 2000). It is assumed in this study that the instruction delivered by Jim must be described with the most frequently observed OTOP

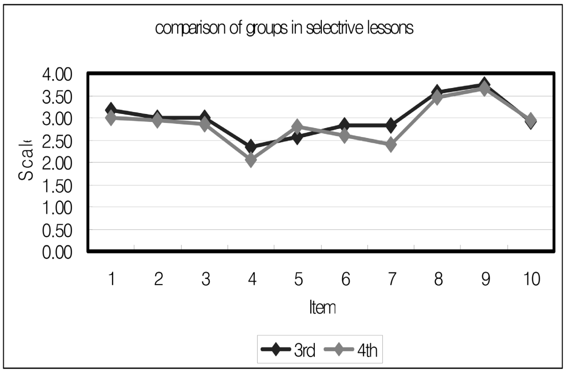

Fig. 1 *Group comparison: third & fourth periods. OTOP items: (1) Habits of mind (2) Metacognition (3) Discourse and group work (4) Challenging ideas (5) Misconception (6) Conceptual thinking (7) Divergent thinking (8) Interdisciplinary connection (9) Pedagogical Content Knowledge (10) Concrete material use*

items: #4 (challenging ideas), #6 (conceptual thinking), and #7 (divergent thinking), since Jim displayed the developed understandings about scientific argumentation as well as inquiry envisioned by the *Standards.*

The OTOP data from ten hours each of two different classroom observations from the content of Newton's Law through Claim-Evidence Approach (CLEA) were compared. Two blocks of Jim's classes for the same content were observed for the reliability of data collection (Fig 1).

Looking at the two different blocks of students compared using OTOP shown in Fig 1, there was commonality in the teaching pattern of Jim's lessons with the emphasis on argumentation strategy, CLEA. Jim used many questions to assess his students' prior knowledge or misconceptions—using OTOP #3 (Discourse and group work), #4 (Challenging ideas), and #5 (Misconception)—in each lesson where students developed their background information for CLEA. He provided open-ended questions for students to provide alternative opinions—using #1 (Habits of mind), #6 (Conceptual thinking), and #7 (Divergent thinking)—and encourages students to express their ideas or demonstrate reasoning skills, using #2 (Metacognition). Jim helped students develop their background knowledge through reading the textbook and transforming the data into other representations, such as bar graphs or drawings, using #8 (Interdisciplinary connection). In addition, he used appropriate information or knowledge in helping students understand the content and employed different discursive practices, appealing to #9 (Pedagogical Content Knowledge). Finally, Jim used visual tools, such as videos or slides, in delivering the content, while also using concrete materials for students' experiments, fulfilling #10 (Concrete material use). Here is an example how Jim implemented CLEA for students' argumentation in the content of Newton's Law.

Jim used this approach for students' content learning. First, Jim used a science textbook to develop background information about the Newton's first and second laws. Jim worked with students to introduce them with new scientific terms of Newton's law through reading page by page. When Jim encountered new terms which students need to learn, he paused for students to write them down on their notebooks. After one sessions of each chapter, Jim gave papers, which was called "review and reinforce" worksheet, and students had chances to review what they learned in definitions or properties of new terms based on their readings. This entire process was aimed to develop background information before implementing CLEA. For example, students develop their basic concepts of new terms (ex: motion, reference point, speed, constant speed, average speed, velocity, acceleration, calculating or graphing acceleration, force, balanced or unbalanced force, etc.) as their basic background information for the next activity.

Then, students develop their "CLAIM" based on their readings of textbook. This stage is called ***"Framing Investigation."*** For example, in the textbook, we can read "Newton's first law of motion states that an object at rest will remain at rest. In addition, the object that is moving at constant speed will continue moving as constant speed unless acted upon by an unbalanced force." Jim provided students to develop their own "claims" based on their readings from textbook about Newton's first law with the use of their language and understandings from their prior background information which they had just now covered. Each student has own its claims to be tested and related to Newton's first law. Now, Jim demonstrated how rocket balloon can work with the use of balloon and straws. Then, he motivated students to observe and find out the relationship between the balloon's hovering time in the air and the length of straws. Then, Jim provided exact procedures for students to follow up. Students in each group got the same materials and data table sheets to test which length can make the rocket balloon hover longest time. The time of hovering and observations from each length of nozzles (straws) was different and recorded in the data tables. Before the activity, Jim worked on dependent and independent variables needed to ***"Design Investigation."*** They had chance to discuss which variables can be independent and dependent.

Students collected data and recorded them with the observations in the given data tables. Then, Jim worked on transferring data to other representations, Graphing, to ***"Interpret the Pattern of Data."*** Based on the collected data from each group, Jim worked on transferring data to representation of graphing. Jim also provided opportunities for students to interpret and discover the pattern of the data. Jim provided a specific guide for writing the lab reports.

1. Report the results
2. Identify patterns.
3. Talk about what you think happened and why
4. look over your design and tell of anything that cause a problem
5. Write a conclusion that tells
   A. What was the question and the claim
   B. If what you thought would happened and how you know.
   C. How the problems could be solved.
   D. What is another experiment you would do with this equipment?

After this writing up, students had chance to talk about the limitations and share ideas about how to improve the activity by overcoming those limitations. At the end of activity, Jim had an opportunity to talk about scoring guide to let students know how their lab reports would be scored.

It is concluded that Jim provided students with many opportunities to demonstrate their reasoning skills. Examples of students' opportunities to reason in Jim's classes included: how to gather background information, how to frame questions based on the information, how to differentiate the independent from the dependent variables in each lab activity, how to differentiate evidence from data, how to use evidence to support the questions they developed, and how to create better experiments in a new context by overcoming the previous limitations.

V. Conclusions and Implications

This study investigated the secondary science teachers' understandings about scientific argumentation in the context of scientific inquiry and their explicit teaching strategies for the purpose of its implementation in the classroom. Based on the results, some conclusions and implications are made as follows.

First, all teachers participated in this study displayed their understandings about the essential features of scientific inquiry in the classroom. All teachers participating in this study were leaders, representatives of each county, and they had worked with science educators for the purpose of creating explicit teaching strategies to provide students with opportunities of developing argumentation for four years through professional teaching programs under the theme of "scientific inquiry summer institute." All participants had chances to reflect on their understandings about the essentials of scientific inquiry and made efforts to create new models or teaching strategies with the aim of providing students with the ability to "make their voices" logically and critically. All participants define scientific inquiry as the opportunity for students to present their arguments and criticisms logically based on evidence collected through experimentation.

Second, there was a difference in teachers' understandings about scientific inquiry, depending on different teaching levels. Even though all participants were exemplary and they displayed the structured understandings about scientific inquiry, teachers at upper elementary levels regarded scientific inquiry as pieces of procedural skills of inquiry, while teachers at middle levels regarded scientific inquiry in a holistic way. Therefore, the UESTs emphasized students' developing inquiry skills as pieces during each inquiry lesson, such as developing/framing inquiry questions. They stressed that it is critical that students have the opportunity to design simple investigation skills step by step. The UESTs would say that students at elementary levels are not ready to develop their argumentation enough to form logical thought processes, so it is more important for them to use inquiry procedural skills rather than scientific thinking skills such as criticism. On the other hand, the MSTs emphasized the students' abilities to support or refute certain positions during their argumentation beyond their procedural inquiry skills, indicating that students need to know how to use the evidence from experimentation to develop theories or claims in order to understand the nature of scientific inquiry.

Third, it is critical to develop explicit teaching strategy to create opportunities to practice argumentation in the context of scientific inquiry. CLEA is a teaching strategy which allows students to make their voice through argumentation. All the participants agreed that CLEA was very successful in meeting this goal.

When an instructor's understandings or beliefs about teaching science influence the practice of providing students with opportunities for scientific argumentation, it is pivotal to examine their understandings before examining their instructional practices. This study investigated some of the general understandings about scientific argumentation displayed by exemplary teachers, each of whom has shown much interest in learning new teaching strategies for providing students with opportunities of scientific argumentation. Their generalizable developed understandings about scientific argumentation will be the basis for investigating teaching strategies. These exemplary science teachers' understandings about argumentation as well as inquiry can be used as a guideline for other currently employed teachers to refer to through professional development programs. Correspondingly, if teachers at universities begin to form their knowledge in the early stage of their teaching careers, it is important to provide them with opportunities to reflect on and develop a firm understanding of scientific argumentation as well as inquiry teaching as early as possible. In terms of teacher professionals, this result has meaningful implications in pre-service and in-service teacher education.

These results could be implemented into the Korean science education system. Beginning teachers whom I met through professional development program displayed the unstructured understandings about scientific argumentation in terms of scientific inquiry. It is very necessary for science teachers to have chances to reflect on their understandings about inquiry as well as argumentation as long as they have intention to create the environment where students experience freely how scientific knowledge is constructed in the classroom.

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Appendix 1 (interview protocol)

1. *How do you define scientific inquiry in your classroom?*
2. *How does scientific inquiry differ from hands-on activities?*
3. *How do students develop their reasoning skills with scientific inquiry?*
4. *How do teachers support students to develop their scientific thinking? Do you have any specific or explicit teaching instruction or model that you designed for this purpose in the classroom?*
5. *If any, would you give examples in which you felt that students were successful in demonstrating their scientific thinking/reasoning skills using scientific argumentation?*
6. *What makes it difficult for students to express reasoning in science?*
7. *What are some criteria for students' successful expressing reasoning in science?*

Appendix 2

OCEPT-Teacher Observation Protocol (O-TOP)
Outcomes Research Study – 2005

This instrument is to be completed following observation of classroom instruction. Prior to instruction, the observer will review planning for the lesson with the instructor. During the lesson, the observer will write an anecdotal narrative describing the lesson and then complete this instrument. Each of the ten items should be rated 'globally'; the descriptors are possible indicators, not a required 'check-off' list.

	Not Observed				Characterizes Lesson
1. This lesson encouraged students to seek and value various modes of investigation or problem solving (Focus: Habits of Mind)	**N/O**	1	2	3	4
Teacher/Instructor: Presented open-ended questions Encouraged discussion of alternative explanations Presented inquiry opportunities for students Provided alternative learning strategies Students: Discussed problem-solving strategies Posed questions and relevant means for investigating Shared ideas about investigations					
2. Teacher encouraged students to be reflective about their learning. (Focus: Metacognition – students' thinking about their own thinking)	**N/O**	1	2	3	4
Teacher/Instructor: Encouraged students to explain their understanding of concepts Encouraged students to explain in own words both what and how they learned Routinely asked for student input and questions Students: Discussed what they understood from the class and how they learned it Identified anything unclear to them Reflected on and evaluated their own progress toward understanding					

3. Interactions reflected collaborative working relationships and productive discourse among students and between teacher/instructor and students.(Focus: Student discourse and collaboration)	**N/O**	1	2	3	4
Teacher/Instructor: Organized students for group work Interacted with small groups Provided clear outcomes for group Students: Worked collaboratively or cooperatively to accomplish work relevant to task Exchanged ideas related to lesson with peers and teacher					
4. Intellectual rigor, constructive criticism, and the challenging of ideas were valued. (Focus: Rigorously challenged ideas)	**N/O**	1	2	3	4
Teacher/Instructor: Encouraged input and challenged students' ideas Was non-judgmental of student opinions Solicited alternative explanations Students: Provided evidence-based arguments Listened critically to others' explanations Discussed/Challenged others' explanations					
5. The instructional strategies and activities probed students' existing knowledge and preconceptions.(Focus: Student preconceptions and misconceptions)	**N/O**	1	2	3	4
Teacher/Instructor: Pre-assessed students for their thinking and knowledge Helped students confront and/or build on their ideas Refocused lesson based on student ideas to meet needs Students: Expressed ideas even when incorrect or different from the ideas of other students Responded to the ideas of other students					
6. The lesson promoted strongly coherent conceptual understanding in the context of clear learning goals.(Focus: Conceptual thinking)	**N/O**	1	2	3	4
Teacher/Instructor: Asked higher level questions Encouraged students to extend concepts and skills Related integral ideas to broader concepts Students: Asked and answered higher level questions Related subordinate ideas to broader concept					
7. Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence. (Focus: Divergent thinking)	**N/O**	1	2	3	4

Teacher/Instructor: Accepted multiple responses to problem-solving situations Provided example evidence for student interpretation Encouraged students to challenge the text as well as each other Students: Generated conjectures and alternate interpretations Critiqued alternate solution strategies of teacher and peers	
8. Appropriate connections were made between content and other curricular areas. (Focus: Interdisciplinary connections)	**N/O** 1 2 3 4
Teacher/Instructor: Integrated content with other curricular areas Applied content to real-world situations Students: Made connections with other content areas Made connections between content and personal life	
9. The teacher/instructor had a solid grasp of the subject matter content and how to teach it. (Focus: Pedagogical content knowledge)	**N/O** 1 2 3 4
Teacher/Instructor: Presented information that was accurate and appropriate to student cognitive level Selected strategies that made content understandable to students Was able to field student questions in a way that encouraged more questions Recognized students' ideas even when vaguely articulated Students: Responded to instruction with ideas relevant to target content Appeared to be engaged with lesson content	
10. The teacher/instructor used a variety of means to represent concepts. (Focus: Multiple representations of concepts)	**N/O** 1 2 3 4
Teacher/Instructor: Used multiple methods, strategies and teaching styles to explain a concept Used various materials to foster student understanding (models, drawings, graphs, concrete materials, manipulatives, etc.)	