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THE OPPORTUNITY OF SCIENTIFIC ARGUMENTATION IN THE CLASSROOM: CLAIM-EVIDENCE APPROACH

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Abstract:
Scientific inquiry is one of the ways that students understand how scientific knowledge is constructed. The purpose of this study was to analyze one science teacher's understandings and his explicit teaching strategies for student argumentation in the classroom. One middle school science teacher and his students of 54 participated in this study. Data were collected through three times of semi-structured interviews, 60 hours of classroom observations, and two times of students' lab reports for eight weeks. Three different argument analyzing tools were employed to develop Scientific Argumentation Table (SAT) and analyze student discourse as responses to those explicit teaching strategies. The results indicated that teacher defined scientific inquiry as the combination of students' hands-on activity and the abilities of reasoning skills. Claim-Evidence Approach provided students with opportunities to develop their own claims based on their readings, design the investigation for evidences, and differentiate evidences from data to support their claims and refute others. The teacher's role of scaffolding was critical to shift students' less extensive to more extensive argumentation through his prompts and questions. The teacher's involvement, his explicit teaching strategy, and students' scientific knowledge influenced students' abilities of developing argumentation and its quality.

Keywords: Claim-Evidence Approach, Scientific argumentation, Procedural skill, Reasoning skill, Scientific inquiry, Scientific literacy, Toulmin's approach

1. Introduction

Gallagher & Tobin (1987) stated that scientific inquiry in K-12 classrooms tends to be procedural lacking opportunities to understand how scientific knowledge is constructed through reflection, debate, and argument [3]. 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 for everyone. The view is that everyone needs to use scientific information to make choices that arise every day. For this purpose, the *National Science Education Standards* by National Research Council 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 [12][13]. To solve this problem, recent research has focused on how to support student opportunities to learn scientific argumentation in the context of scientific inquiry.

The most important finding from current studies about student argumentation is the lack of opportunities for them to make argumentation in the classroom to learn science and about science. That is, there is a general lack of pedagogical expertise among science teachers in organizing activities in which students are given a voice. Therefore, it is important to improve teachers' knowledge, awareness, and competence in managing student participation in discussion and argumentation as well as to enhance the argument skills of young people. For this purpose, it is necessary to know what kinds of teaching strategies are effective or ineffective at enhancing students' argumentation or not in the classroom. The research questions that guided the investigation are as follows:

1. What is teacher's knowledge of scientific argumentation?
2. What kinds of instructional strategies are emerging when the teacher scaffolds student argumentation?
3. How do students respond to these strategies?

2. Theoretical Background

Many studies in science education have found that many scientific inquiry practices implemented in the classroom require only low cognitive thinking processes or are just cookbook type activities without opportunities for students to truly understand and explore the nature and limitations of scientific knowledge building [3][7]. Gallagher and Tobin (1987) reported that inquiry process was presented as a recipe, asking students to follow steps without applying reasoning skills [3]. Krajcik et al. (1998) also reported that students did not use opportunities to draw conclusions by reflecting on their data and questions. Some students in groups drew conclusions based on their experience rather than their data [7].

The *Standards* are clear when they advise educators that scientific inquiry is not a hands-on activity. Getting students to understand science as inquiry requires minds-on activities such as argumentation, explanation, and communication of results as well as hands-on activities of experimentation and exploration. What does student argumentation in the classroom mean? Newton, and 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 will further enhance the public understanding of science and therefore improve scientific literacy [1]. Kuhn stated that we should experience science as argumentation as well as science as exploration in order to understand the scientific thinking of scientists; students' scientific thinking can be developed best when they practice describing and justifying theories, presenting alternative theories, presenting counter-arguments, and providing rebuttals through argumentation with peers and teachers [8] [11]. For example, Vellom and Anderson (1999) investigated sixth graders' argumentation through small and whole class group work, using the concept of density as the content of the instruction [17]. The study's findings indicated that (a) through argumentation with peers and teachers, students reached one agreed-upon theory by sharing their supporting or refuting evidence from their investigation, and (b) students had opportunities to discuss experimental techniques and replication and to assess whether a particular scientific claim or fact fits into a larger pattern of data and theory. By developing argumentation with peers and teachers, students were shown to learn science concepts in the context of scientific inquiry through argumentation based on their observations and experimentation.

Then what kind of teaching strategies are effective in enhancing students' understanding of how scientific knowledge is constructed through argumentation? A pivotal teaching strategy for teachers that provides students with the opportunity for argumentation is using small group activities with peers or teachers, where they interact one another to reflect on their prior knowledge. At this time, students are expected to demonstrate their scientific thinking skills while developing scientific argumentation.

Kuhn (1989) 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 [10]. She describes a scientific thinker as someone who (a) is able to consciously articulate a theory that scientists accept, (b) knows what evidence could support the theory and what evidence could contradict it, and (c) is able to justify why the coordination of theories and evidence has led scientists to accept a theory or reject others regarding the same phenomenon (p 674). On the basis of this definition of scientific thinking, Kuhn and other researchers (Klahr & Kotovsky, 1989) investigated the process of scientific thinking and obtained results that suggest that there are significantly different thinking processes among children, lay adults, and scientists [6] [9] [10].

Students need to develop those scientific thinking skills, such as the ability to differentiate evidence from data, during their scientific inquiry lessons at school. Scientific thinking skills are achieved through argumentation practices regarding a certain scientific concept in the context of scientific inquiry [2]. For this purpose, teachers need to provide students with opportunities to develop conceptual understanding, to develop investigative competence, and to understand the epistemology of science. Hogan, Nastasi, and Pressley (2000) and Yerrick (2000) showed how teachers' roles in scaffolding could promote students' argumentation in order to develop their scientific thinking skills during scientific inquiry activities [15] [18]. In the scaffolding process, teachers pose questions, not to evaluate but to discover what students already know and what ideas students are struggling with. Pressley, Hogan, Wharton-McDonald, Mistretta, & Ettenberger, pointed out that teachers' prompts intend to help students gain understanding rather than simply evaluate what they are learning [15].

Recent research has investigated few opportunities for students' developing scientific argumentation or opportunities of demanding low cognition to understand the nature of scientific knowledge. The research has also investigated teaching strategies that provide students with opportunities to develop argumentation skills. The research also implies that teachers can encourage students to demonstrate scientific thinking skills by providing them with opportunities for developing argumentation through instructional curriculum. However, there is little research on what kind of function or models of explicit teaching strategies teachers employ for student argumentation and how students respond to those teaching strategies. It can be assumed that the quality of student argumentation differs in response to teachers' different explicit teaching strategies.

3. Methodology

3.1 Educational Setting

The researcher worked with a science teacher, referred to here as Mr. Field, who teaches seventh-grade science at a public middle school in a coastal Northwestern city. That city has a population of 9960 and its major industries include fishing, wood products, and tourism. The middle school where Mr. Field works has 446 enrolled students from grades six to eight. The socioeconomic status (SES) based on the number of students receiving free or reduced-price lunch is 44% compared to the state average of 39%. Student ethnicity is 85% White and 15% other races, including Asian (2%), Hispanic (7%), American Indian (6%), and African American (1%). In the State Assessment, this middle school ranked above the state average in reading (73% to the state average of 64%) and writing (70% to the state average of 66%), but below average in math (52% to the state average of 57%).

The researcher observed two units of instruction that were taught to two different periods of seventh-grade students in the same classroom. There were 27 students in each classroom and 50% of them received free or reduced-price lunch, which is higher than the school's average of 44%. The two classes had similar average academic levels. The students sat at seven different tables in groups of four and there was a separate table for the researcher to observe from. Three groups consisted of students whose parents gave permission for their child to participate in this study.

3.2 Participants

One science teacher, Mr. Field, and his students, 54 in two classrooms, at the middle school level (7^{th} grade) participated in this study for two months. Mr. Field taught science content for 30 years at upper elementary and middle school levels. Mr. Field also attends professional development programs regularly two or three times per year with the aims of (a) completing his school district's Science Curriculum Science Guide, (b) working with elementary and middle school teachers to implement inquiry-based learning opportunities, and (c) developing opportunities for teachers to use the Standard Based Science Tests to assess strengths and weaknesses of science content. Students included three ESL (English Second Language), two IEP (Individualized Educational Program) who had emotional disabilities, and one TAG (Talented And Gifted) students in two classrooms.

3.3 Data Collection

Three interviews employing semi-structured interview protocols were used to examine Mr. Field's understanding of scientific argumentation. There were first interview (entering: Appendix 1) protocols, asking his general understanding about scientific argumentation in the classroom, second interview triangulating his teaching strategies observed during class observations, and third interview (exiting) validating the results of this study based on the researcher's data analysis. Observational protocols (OTOP: Appendix 2) with field notes were employed to observe and investigate Mr. Field's teaching strategies that led students to demonstrate scientific thinking skills for 60 hours of lessons. 60 hours of class observations were all video-audio-taped for transcription later.

3.4 Data Analysis

Transcriptions of Mr. Field's interviews were used to generalize his understandings about scientific argumentation based on interview protocols through coding categories. 23 hours out of it were analyzed by Toulmin's approach (1958) to see how much students' discourse was argumentative. Two different units of students' lab reports were also collected to analyze by Toulmin's approach to decide the quality of students' abilities of developing scientific argumentation [16].

4. Results

4.1 Mr. Field's Understandings about Scientific Argumentation

Mr. Field defined scientific inquiry as the combination of developing procedural skills through hands-on activities and reasoning skills through argumentation. He also differentiated scientific inquiry from hands-on activity in that scientific inquiry is the combination of hands-on activity and the opportunity of using reasoning skills.

Mr. Field believed that the limited students' scientific knowledge is the barrier preventing students demonstrating their reasoning skills in constructing their knowledge during the lesson. However, Mr. Field believes that students at the seventh-grade level can develop the reasoning skills needed to perform and understand scientific inquiry by practicing using reasoning with a teacher's guidance and discipline. To meet this goal, Mr. Field uses some explicit teaching strategies to provide students with opportunities to demonstrate and promote their reasoning skills based on scientific investigation. Mr. Field believes that it is possible for students to develop reasoning as well as procedural skills through the practice of doing scientific inquiry activities.

Mr. Field added that students at this age (12 or 13 years old) are developmentally beginning to understand the mechanism of cause-and-effect thinking. Mr. Field responses that it is his role to scaffold lessons at this point to allow students to practice scientific thinking and argumentation, in order to understand how scientific knowledge is constructed.

4.2 Explicit Teaching Strategy for Scientific Argumentation: Claim-Evidence Approach

The *Claim-Evidence Approach* (CLEA) is the main teaching strategy that Mr. Field employed for students' learning. This approach has two features. First, this approach is a deductive method for students to establish scientific claims based on their readings in the textbook or other sources. Second, this approach provides students with opportunities to develop evidence-based arguments that support or refute claims.

First, Mr. Field used the textbook to develop background information about Newton's laws. The students learned new terms related to Newton's laws by reading the textbook. Then, students develop their own claims using their own words based on the background information from the textbook (Kahan, 2000) about Newton's first law: *Newton's first law of motion states that an object at rest will remain at rest. And an object that is moving at constant speed will continue moving at constant speed unless acted upon by an unbalanced force* (p. 48). Along with having students develop their own claims, Mr. Field encouraged students to develop their own research questions or hypotheses and to design and carry out the experiments to find the answer to those questions. The following excerpt shows Mr. Field's understanding of how important it is for students to use their own voices and subjectivities in designing the investigation.

During the lesson, Mr. Field explained what CLEA is and how students develop a claim generally by saying, "*Inquiry means thinking creatively,*" or *"You start with an idea."* Mr. Field also displayed his holistic understanding of the nature of scientific inquiry and the nature of science in terms of the subjectivity and creativity needed to develop claims by saying, "*[Claims] must be true... What if it is not true?"* and *"You put it in your own words that make sense to you."*

Mr. Field scaffolded students to develop their own claims by repeating definitions, giving concrete examples, and extending the knowledge needed for students to use in developing their own claims for the purpose of providing students with opportunities of developing argumentation. Mr. Field contextualized and demonstrated one simple activity so that students were motivated to think of the variables and knowledge needed to develop their own claims by saying, *"If I put my rocket balloon here…"* and *"there is some energy added to it."* This step of CLEA is called *Framing the Investigation.*

Second, Mr. Field introduced the *Rocket Balloon Activity* lab and demonstrated a simple activity with concrete materials. After his demonstration for students' observation, Mr. Field worked on helping students understand which variables would be dependent or independent in carrying out the rocket balloon activity. This step of the CLEA instruction is *Design the Investigation* and is when students design the lab activity, also including smaller steps such as demonstrations for class observation, discovering dependent and independent variables needed to design the experiment, and collecting and transforming the data.

Third, Mr. Field encouraged students to analyze the data and find evidence to support their claims based on their patterns of data. If students could not find any pattern or any evidence that could refute their claims, they had another opportunity to developing an argument about why this happened and how this limitation could be overcome to make this experiment better. The last phase of CLEA, *Analyzing and Interpreting Results*, occurred at the end of the inquiry activity and was performed through students' writing rather than whole class discussion. During this phase, Mr. Field had chances to discuss what students should discuss and write in their lab report under Inquiry Guideline developed by him. Mr. Field explained what students should report in their results, and implied that students need to use their own evidence (data) that they collected from their experiments to describe what happened in the results section of the lab report. Mr. Field emphasized the importance of using evidence that students collected themselves through experimentation in order to support their claims and hypotheses. Mr. Field also encouraged students to understand in what ways that evidence (data) supported their claims or did not, thereby developing students' argumentation. Mr. Field expected his students to understand what evidence they could use to support their own claims, how they could explain what happened using evidence, and how students could connect those results or conclusions to their own hypotheses or questions that were derived from their claims. Furthermore, Mr. Field provided opportunities for students to extend their thinking skills by describing the patterns of data to *generally explain* the mechanism of what happened as well as reporting their exact evidence to be used to *justify* what happened. During this process, Mr. Field encouraged students to think of any factor which limited their experiment in terms of getting evidence (data) refuting their claims. This step of CLEA is called *Analyzing and Interpreting Results* and is considered to be the most important stage in which students develop their reasoning skills by sharing ideas with peers in groups or with the teacher as a whole class.

4.3 Student Discourse as Response to Claim-Evidence Approach

The transcripts of the 23 sample lessons out of 60 consisted of students' argumentation between Mr. Field and his students, not among students in groups. The definitions of each component and its uses in *Toulmin's* approach as follows. Toulmin's logical approach (1958, Figure 1) was used to examine the students' abilities to think scientifically. Toulmin's approach (Figure 2) for analyzing argumentation includes six components: *Data, Claim, Warrant, Qualifier, Rebuttal,* and *Backing* [15].

Data	**Facts as evidence** from prior knowledge, observations or experimentation for the conclusions
Claim	**Conclusion** to be established
Warrant	**Rules that develop the relationship** between Claim and Data.
Qualifiers	Making Warrant **stronger** with merits
Rebuttal	Making Warrant **weaker** with not-merits
Backing	**General** conditions to the warrants.

Figure 1: Components of Toulmin's Approach

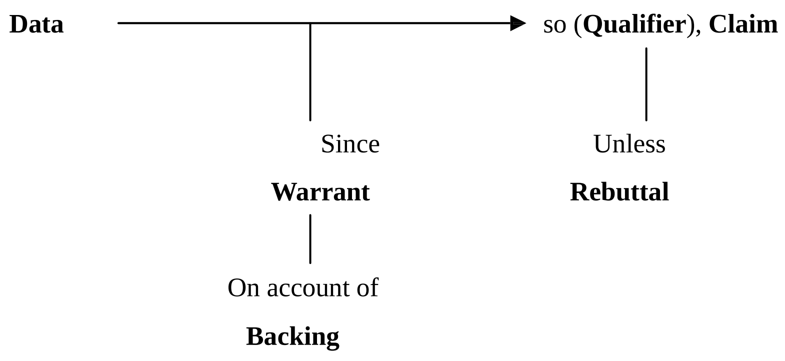

Figure 2: Toulmin's layout of arguments

On the basis of this approach, the researcher investigated how Mr. Field's and his students' discourse fits into these six components.

At the beginning phase of CLEA, Mr. Field made questions so that students were able to answer with one-word answers about variables needed to design the investigation. Here, Mr. Field asked what variables need to be controlled to design this investigation. All of the responses by students at this point were *Claims* in the *Toulmin* system. Mr. Field asked his students to come up with factors that would make *Rocket Balloon* stay longest in the air. To this question, students responded, "Acceleration," "Time," "Distance," and "Force," as *Data* arguments. Mr. Field repeated students' answers and then kept asking for more factors. When one student responded with a factor, "Motion," Mr. Field asked the student to find a better word without giving the student more information. At this time, another student replaced "Motion" with "Energy," and then Mr. Field repeated it. This discourse between Mr. Field and his students during CLEA displayed the less extensive case of argumentation consisting of questions, answers, and evaluation. Overall, the discourse between Mr. Field and his students consisted of the teacher's question, students' answers providing a *Claim*, and then the teacher's evaluation without more explanation, which could be called the *Warrant*.

Students, however, later had more opportunities to develop extensive arguments during the last phase of CLEA, where Mr. Field led students to discuss the factors that made it possible or impossible for the balloon to stay longest in the air. Mr. Field checked if students had collected evidence from their experiments in the *Rocket Balloon Activity* under the *Inquiry Guideline*. Mr. Field regarded the amount of tape students used as one of the factors influencing the balloon's flight, and he asked why the smallest amount of tape was needed to make the balloon stay in the air longer. This argument, a *Qualifier* (the *smallest amount* of tape makes the balloon stay in the air longer), strengthened the relationship between *Data* (the amount of tape) and *Claim* (the amount of tape used to hold the nozzle to the balloon).

At this time, Mr. Field furthered the discussion by asking students more about the force involved in pulling the balloon downward. Mr. Field reminded students of the definition of the force of gravity, *You are talking about some force here. What force are you talking about?* Mr. Field confirmed students' understandings about the definition of the force of gravity, *You are talking about the force of gravity and you seem to think that if something weighs more, the force of gravity pulls on it more. Is that right?* Then, Mr. Field provided an example from the real world to help students understand the properties of gravity by prompting, *OK, is that what you all think? If I went to the top of the school and I dropped a golf ball and I dropped a ping pong ball, the golf ball would hit the ground before the ping pong* *ball*. Mr. Field stated the two conflicting theories about gravity, which prompted students to find more evidence based on their prior knowledge and experience to support one theory or to refute the opposing one. Mr. Field began the argument with one theory: *OK, some of you believe that gravity pulls on everything with exactly the same amount of force*. In response to his instruction, a few students confirmed their understanding about gravity with their opinions, *It depends on what the mass is* or *It depends on how much [it weighs]*. These *Qualifiers* offered by students were possible because Mr. Field created the discussion about gravity. One student provided an opposing theory as a *Rebuttal*, saying *In space you can drop a hammer and a feather and they will land on the ground at the same time.* As response to these two opposing theories about gravity, either that it is constant or dependent on mass, Mr. Field gave a demonstration to show how gravity is constant. The teacher's demonstration led students to reason based on their observations, and Mr. Field concluded that gravity is constant because the two balls landed at the same time. During this discussion, students used *Qualifiers* and *Rebuttals*, creating a more extended form of argument.

In terms of the *Toulmin* analysis in this study, total student argumentation in response to Mr. Field's teaching strategies consisted of *Data* (51% out of 1532 total argument elements, that is, 23 hours of transcription), *Warrant* (21%), and *Claims* (13%) as making up the more frequent case of argumentation relative to the other components: *Qualifier* (9%), *Rebuttal* (4%), and *Backing* (2%). These percentages display *weak* or *less extensive argument forms.* This means that Mr. Field's CLEA focused on providing students with many brief but less developed opportunities to practice scientific discourse.

5. Discussion and Conclusion

First of all, she students' abilities to develop scientific argumentation were related to their levels of scientific knowledge. The student writing argumentation, lab reports, was also analyzed and it proved that students' abilities of developing argumentation had the relationship with their learning achievements. Students completed the lab report under the *Inquiry Guideline* (Appendix 4) developed by Mr. Field, which gave students practice developing written arguments that included all six components of *Toulmin's* approach. The levels of students' written argumentation from lab reports, however, were divided into three levels, **Complete, Partial,** and **Limited**, based on a full score of five. Mr. Field validated this conclusion through his last interview. The higher achieving students proved to be qualified to demonstrate their reasoning skills through using appropriate evidences to support their claims to explain the phenomenon. The lower achievers proved to have limited scientific terms and knowledge to justify their phenomenon with their own collected evidences. The interaction among students can imply the development of students' cognitive abilities in social settings for future study.

Second, the teacher's more involvement in interacting with students provided them with opportunities of demonstrating their reasoning skills. Students' argumentation opportunities were promoted when Mr. Field engaged in guiding students to extend their knowledge or skills by prompting, questioning, and giving clues. Two different types of argumentation emerged (a) *fundamental argumentation*, consisting of the teacher's initial questions, students' responses to them, and teacher's evaluation; and (b) *exploring argumentation,* when Mr. Field provided extended knowledge and supported more complex skills.

In *fundamental argumentation*, there is a linear pattern of discourse consisting of a two-part question-answer structure or a three-part question-answer-evaluation structure, called "Triadic Dialogue" by Lemke [12]. *Fundamental* *argumentation* uses the linear flow as diagrammed in Figure 5.

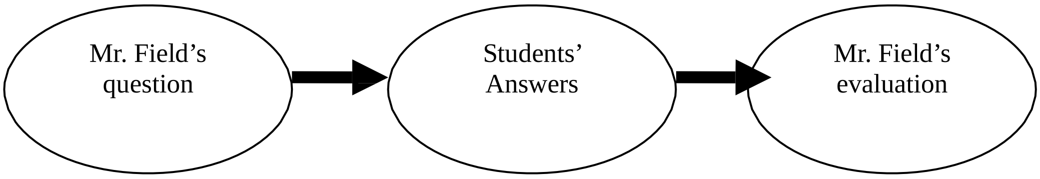

Figure 5: Fundamental Argumentation

In *exploring argumentation*, there is a circular pattern of discourse rather than a linear one (Figure 6). Mr. Field created a question, students answered it, Mr. Field evaluated their answers with more questions or prompts, and students developed extended argumentation in response to Mr. Field's instruction. Mr. Field then synthesized all content based on students' ideas. The students often developed a higher quality of argument by offering alternative or contrasting points of view. This mutual interaction between the teacher and students takes place as a circular argument, *exploring argumentation*, represented in Figure 6.

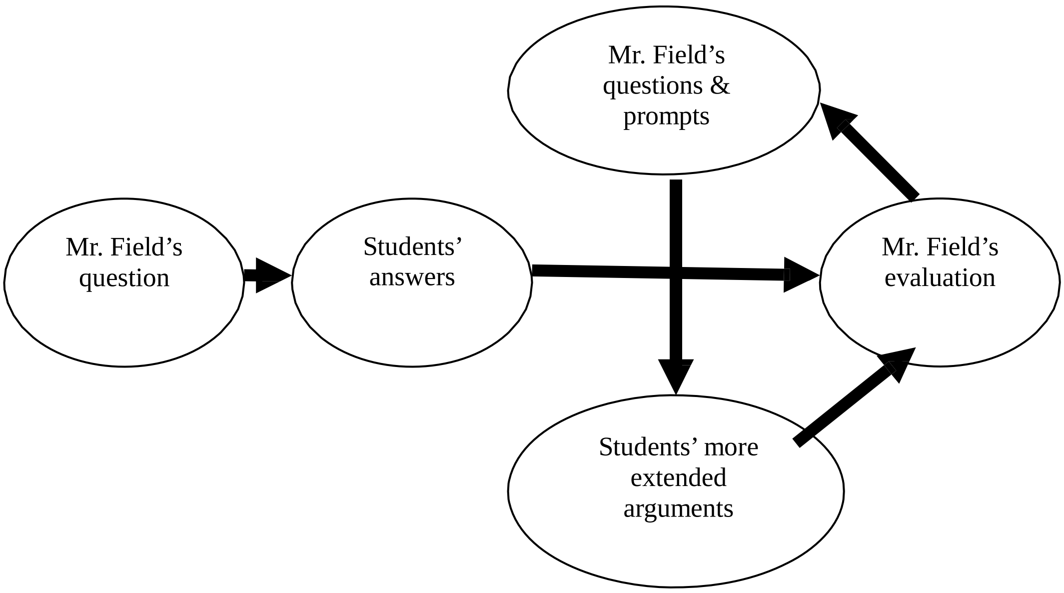

Figure 6: Exploring Argumentation

It is implied that students could have more of a chance to develop a higher quality of argumentation with more teacher involvement and interaction with students. It is clear that teacher involvement in students' expression of scientific argumentation improved the quality of argumentation. That is, the teacher's active engagement guided students to a higher quality of argumentation by shifting the form of argument from *fundamental argumentation* to *exploring argumentation*. In this study, students were able to justify their claims with the use of evidence through Mr. Field's use of extended content and demonstrations in his role as a mentor and a facilitator.

Third, the explicit teaching strategy, *Claim-Evidence Approach* which was designed and implemented for the purpose of providing more opportunities of developing argumentation, was successful to meet its goal. The developed explicit teaching strategy can be used as a guide for teachers to learn through professional development program, including induction program for beginning teachers, preparation program for preservice teachers. In addition, the research methodology, Toulmin's approach for student discourse analysis, made it possible to view the interaction between teacher and students to see how the teacher helped students develop argumentation. Since there is mutual interaction between the teacher and students (or among students) that in turn influences consecutive arguments, it is necessary to analyze interpersonal discourse in the context of a social setting. This methodology can be also useful for teachers and educators to design curriculums providing the opportunities of argumentation. Further investigation of students' abilities to develop scientific argumentation in different contexts, such as group work and whole class discussion, is recommended with the use of the argument analysis tool employed in this study, in order to better understand the nature of learning and teaching scientific argumentation in the classroom.

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