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Promoting Argumentative Practice in Socio-Scientific Issues through a Science Inquiry Activity

Younkyeong Nam
Pusan National University, REPUBLIC OF KOREA
Ying-Chih Chen
Arizona State University, UNITED STATES OF AMERICA

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ABSTRACT
This study examines how the use of a science inquiry activity in an environmental socio-scientific issue (SSI) impacts pre-service teachers' argumentative practice in two ways: social negotiation and epistemic understanding of arguments. Twenty pre-service science teachers participated in this study as a part of their science methods class. Small group discussions, while participating in an SSI debate, before and after engaging in a science inquiry activity, were collected as a main data source. The data were analyzed by an analytic framework adapted from both Toulmin's (1958) model of argument structure and Walton's (1996) reasoning scheme. The results indicate that the use of a science inquiry activity during SSI debate not only affects the teachers' social negotiation patterns, but also enhances their epistemic understanding. This study suggests that incorporating a science inquiry practice into an SSI debate has the potential to improve students' disciplinary engagement and the quality of their argumentative practice.
Keywords: argumentation, socio-scientific issues, scientific reasoning

INTRODUCTION

Argumentation is recognized as a core practice of science and is advocated as an essential goal of science education in current reform documents (e.g., Common Core State Standards Initiative, 2012; NGSS Lead States, 2013). One way to engage students in argumentative practice is to provide an environment with a socio–scientific issue (SSI) for debate and to make decisions (Dawson & Venville, 2009; Foong & Daniel, 2012; Iordanou, & Constantinou, 2014; Sadler & Donnelly, 2006; Yang & Tsai, 2010). In this context, students can debate their ideas using life experiences, ethical values, and scientific evidence (Steffen & Hößle, 2014). Scholars, such as Sadler (2004) and Means and Voss (1996), claim that socio-scientific issues allow students to formulate positions and provide supporting evidence to make decisions because "the problems are more open-ended, debatable, complex, or ill-structured, and especially when the issue requires that the individual build an argument to support a claim" (Means & Voss, 1996, p.140).

Correspondence: Younkyeong Nam, *Pusan National University, Republic of Korea.*
ynam@pusan.ac.kr

State of the literature

- Socio-scientific issue (SSI) debate engages students in negotiating diverse ideas and formulating positions using life experiences, ethical values, and scientific evidence in order to reach a consensus and make decisions.
- Recent studies report that students participating in socio-scientific issues have fewer opportunities to engage in authentic science inquiry practice through manipulating variables, designing experiments, and gathering data to match evidence.
- While students' reasoning ability to evaluate evidence and how they use that evidence to support their claim is the essence of epistemic understanding of argument, this important component of argument has not been captured well in the SSI debate literature.

Contribution of this paper to the literature

- This study suggests examining students' argumentation in SSI using two dimensions: social negotiation and the epistemic understanding of argument in order to capture the quality of argument in the SSI context.
- By considering both Toulmin's structure (1958) and Walton's reasoning scheme (1996), this study suggests a more comprehensive framework to analyze and evaluate the quality of argument in the SSI context.
- This study illustrates that incorporating an authentic science inquiry practice embedded within the SSI context could improve students' science disciplinary engagement and the quality of their argumentative practice.

However, recent studies report that students who engage in activities related to SSI usually focus on realizing moral, ethical, and political considerations associated with the application of scientific knowledge, rather than arguments for constructing an understanding of scientific principles or reasoning practices for content (e.g., Cinici, 2016; Zeidler & Sadler, 2008). Cavagnetto (2010) argues that students participating in the debate of socio-scientific issues have fewer opportunities to engage in authentic scientific practice through manipulating variables, designing experiments, and gathering data to match evidence. Osborne, Erduran, and Simon (2004) pointed out that "just giving students scientific or controversial socio-scientific issues to discuss is not sufficient to ensure the practice of valid argument" (p. 997). In addition, a critical limitation of using SSI debate in science classrooms is that students do not have sufficient scientific information to make appropriate decisions, and there is no "right" answer to the problem being argued (Lewis & Leach, 2006).

We recognize the shortcomings of employing SSI debate in science classrooms to foster students' learning of authentic scientific practices, such as collecting scientific evidence or using scientific reasoning to construct scientific explanations, but we also acknowledge the meaningful benefits of SSI debate toward promoting student learning outcomes, such as communication and decision-making skills based on social negotiation. In order to improve students' disciplinary engagement with scientific reasoning and argumentative practice, this study suggests incorporating an authentic science inquiry practice with SSI debate. The opportunity to collect scientific data associated with an SSI and to analyze it to define evidence to support their claim will reinforce students' scientific argumentation capacity and eventually help them make informed decisions about the issues.

The purpose of this study is to examine how an authentic science inquiry experience relevant to an SSI debate affects participants' argumentative practice.

The specific research questions that guided this study are:

1) In what ways does the experience of science inquiry in a SSI debate change the pre-service science teachers' social negotiation pattern?
2) How does the experience of science inquiry activity in SSI debate affect the pre-service science teachers' epistemic understanding of argument?

ANALYTICAL FRAMEWORK

Recently, using SSI in science classrooms has captured the international spotlight, as it provides a meaningful learning environment in which to engage students in scientific argument practices (Jho, Yoon, & Kim, 2014; Khishfe, 2014; Sadler, 2004; Wu & Tsai, 2010). One of the desirable outcomes of participating in the debate of SSI is the improvement of students' scientific literacy through immersing them in debates, critiques, discussions, and negotiations based on evidence (Eggert, Nitsch, Boone, Nückles, & Bögeholz, 2017; Karahan & Roehrig, 2016). As Norris and Phillips (2003) demonstrate, students can integrate and apply a derived sense (i.e., being knowledgeable about science content) and a fundamental sense (i.e., being able to read/write science texts and various modes of representation) of scientific literacy in the SSI environment. This environment engages students in negotiating diverse ideas in order to reach a consensus when they work cooperatively through applying their epistemic understanding of argument toward an issue or a science topic. That is, students are required to use their understanding of what counts as good evidence and what counts as a good claim in this kind of environment to debate, discuss, defend, and debunk (Duschl, 2008; Ryu & Sandoval, 2012, 2015; Sampson, Grooms, & Walker, 2011).

Consequently, we believe that SSI have the potential to provide students with an argumentative environment with two important dimensions: (1) social negotiation: students are able to discuss, defend, and debunk arguments in order to build consensuses and (2) epistemic understanding of argument: students are able to develop understanding about what counts as a good argument and apply that understanding to construct and critique others' (Chen, Hand, & Park, 2016; Ford, 2012). In terms of social negotiation, students are able to construct arguments and share them to gain public critique to understand strengths and weaknesses in those arguments and then to revise them. The construction and critique processes engage students in improving their argument and making better decision. SSI argumentation activities engage students in a decision-making process with the support of evidence and foster their understanding of how informed decisions in socio-scientific issues are made by communities through social negotiation (Iordanou & Constantinou, 2014; Sadler, 2004). Thus, the goal of social negotiation in SSI is not only to persuade opponents to accept an argument, but also to reach a mutually agreed condition through discussing, exchanging, and critiquing claims based on evidence (Cavagnetto & Hand, 2012).

In addition to social negotiation, we consider another important dimension of SSI, which is the epistemic understanding of argument. Epistemic understanding involves the way students consider what good evidence is and how good evidence is constructed. High quality scientific argumentation should involve proposing alternative ideas and supporting those ideas with scientific evidence (Kuhn, 1996; Seung, Choi, & Pestel, 2016). Unfortunately, studies show that students lack the ability to evaluate evidence; students struggle with understanding the nature of scientific evidence, particularly the uncertainty in scientific data and evidence during SSI debate (Fleming, 1986); students hardly recognized the scientific data in an SSI and confused the data with predictions and opinions (Sadler, Chambers, & Zeidler, 2004); students' evaluations were nuanced and based partly on empirical evidence (Kolsto, 2001); individual students' beliefs, values, and emotions play an important role in their reasoning (Jho et al., 2014; Sadler & Zeidler, 2005). Students' lack of ability to evaluate the evidence is a critical problem related to the quality of argument in socio-scientific issues (Acar, Turkmen, & Roychoudhury, 2010).

Students' ability to evaluate evidence and how they use that evidence to support their claim is the essence of epistemic understanding of argument (Berland & Crucet, 2016; Chen, Hand, & McDowell, 2013; McNeill, 2011). In the field of science education, most research concerning argumentation has adapted Toulmin's (1958) model, including claim, grounds, warrants, backings, rebuttals, qualifiers, to analyze and guide students to engage in argumentation (e.g., McNeill, Lizotte, Krajcik, & Marx, 2006; Osborne et al., 2004; Park, 2016). These studies open a fruitful avenue of investigation toward a sophisticated understanding of how students use argument components to engage in scientific discussion. For example, Osborn at al. (2004) use Toulmin's model to investigate the development of argument pattern when teachers implemented argumentation in science classrooms across one year. However, Erdurn (2008) reports that Toulmin's model is too complicated not only for students to use in science classrooms but also for researchers to analyze argumentative dialogue. It is difficult to reliably distinguish some of the components from others such as warrants, backings, and qualifiers. Studies conducted by McNeill and her colleagues (e.g., McNeill et al., 2006; McNeill, 2011) adapted Toulmin's model to only three components to examine how students use argument in science classrooms through dialogue: claim, evidence, and reasoning (evidence is what Toulmin calls grounds; reasoning is the combination of grounds, warrants, and qualifiers in Toulmin's model). Though using a simplified version, they found that problems still remained in evaluating the quality and strength of students' reasoning through Toulmin's structure-based model.

Nussbaum and Nichael (2011) points out that Toulmin's model is primarily used and suitable analyzing argument structure but not the strengths, qualities, logical properties, and nature of particular components containing multiple moral reasoning. Plantin (2005) also critique that Toulmin is more useful for formal "monologue" rather than "dialogue" that involves a a back-and-forth series of reasoning among people. Argumentation in science classrooms often involves a series of reasoning debate, such as deduction, induction, correlation to cause, analogy etc., which are difficult to capture and analyze using Toulmin's model. Park (2016) argue that Toulmin's model alone does not capture the extent to which reasoning involves appropriate justifications or sufficient explanation for a claim and evidence. Duschl (2008) points out, "argumentation is seen as a reasoning strategy and thus also comes under the general reasoning domains of informal logic and critical thinking as well" (p. 163). If one of the critical goals of argumentation is to advance students' scientific reasoning and evaluate the strength of reasoning, then a more nuanced and detailed framework is needed to examine the discourse within argumentative contexts (Cavagnetto & Hand, 2010; Hand, Cavagnetto, Chen, & Park, 2016). Duschl (2008) suggests that we need to move beyond structured dialogue toward a framework that reflects how evidence is constructed and supported by reasoning.

Jonassen and Kim (2010) suggest that one model which demonstrates promise for argumentation in science classrooms is Walton's (1996) reasoning scheme. Walton contents that argumentation is a particular pattern of logical reasoning. In his seminal book Argumentation Schemes for Presumptive Reasoning (1996), he characterizes 24 schemes of reasoning based on his previous work. Each scheme of reasoning represents a unique explanation, support, and persuasion to responding to others within that contexts.

Nussbaum (2011) contends that Walton's framework is partially based on Toulmin's framework but more nuanced on different types of reasoning. Duschl (2008) suggests that the combination of Toulmin's structure (1958) and Walton's reasoning scheme (1996) is a more comprehensive framework for analyzing and evaluating the quality of argument. Therefore, we adopt both Toulmin's structure (1958) and Walton's reasoning scheme (1996) as our framework to analyze and interpret students' epistemic understanding of arguments.

Building on these considerations, the primary objective of this study was to examine participants' discourse in socio-scientific issues in two dimensions (social negotiation and epistemic understanding of argument) before and after they engaged in a science inquiry activity. Participant's epistemic understanding of argument was examined by their use of evidence and types of scientific reasoning skills during the argument.

METHODS

This study utilized a qualitative research method grounded in a constructivist epistemology (Merriam, 1998) to understand how pre-service science teachers' argumentative practices (social negotiation and epistemic understanding of argument) changed after they engaged in the process of collecting evidence from a science inquiry activity.

Context

The SSI debate activity used in this study dealt with a unique, real dam removal project that had recently taken place in the Elwha River Valley in the state of Washington, U.S. Because of its location in a national park, the natural environment of the Elwha River Valley had been protected from environmental degradation for centuries. However, recently, communities living near the river valley had discovered clear evidence of negative impacts on the valley's ecology and natural environment as a result of a dam. Noticeable impacts included a decrease in fish species, floods, sediment accumulation behind the dam, and sediment decrease at the mouth of the Elwha River.

The SSI debate activity was purposefully designed to promote the practice of participant argumentation by providing historic, industrial, and scientific information about different communities associated with the Elwha River Valley. In this SSI, participants could make an important political decision while considering benefits and consequences of the dam removal based on different communities' standpoints. As part of the SSI debate, participants were engaged in a scientific inquiry process using a scaled-down stream table model of the real Elwha River Valley. During the science inquiry process, participants had opportunities to test their hypotheses about the consequences of the dam removal and to concisely predict how dam removal would affect sediment flow on the river by manipulating three variables: water flow, amount of sediment, and speed of dam removal.

The specific instructional phases of the activity and objectives of each phase are described below:

- **Phase 1**, the first round of role play community debate: In this phase, each student was assigned to a community debate group and acted as a representative of one of six communities whose livelihood is critically related to the Elwha River Dam: commercial fisher, geologist, Native American community member, owner of Hydro Power, Inc., an employee of the National Park Service, and a resident of Port Angeles. At the beginning of the debate, each student had the opportunity to explain how his/her community's life is critically related to the dam removal and supported his/her position with a visual aid or historical evidence given by the instructor. During the debate, participants collectively decided whether they would keep the dam or not based on their discussion of the benefits and consequences of its removal.
- **Phase 2**, the science inquiry activity: In this phase, students had the opportunity to collect scientific evidence to support their positions using a physical dam model. This was a real, scaled-down model developed by National Center for Earth-Surface Dynamics (NCED), USA. This model is scaled down by real geographical data from the Elwha River Valley and includes plastic sand instead of real sand to represent accurate weight of sediments in the real context. . The dam model enabled students to simulate the sediment flow by controlling three critical variables: deconstruction rate of dam (plastic foam) at one time, amount of water flow into the lake, amount

of sediment into the lake. By controlling the rate of dam deconstruction, the students were able to predict how they should remove the dam to reduce the impact of the sediment flow. By controlling the amount of sediment they allow into the reservoir (Lake Mill), students could predict what would happen to the delta if they retained the dam. Finally, the students could also simulate how change in seasonal precipitation would affect sediment flow down to the steam by controlling amount of water into the lake. Before the students began their experiment, the teacher asked them to make their own hypothesis about what would happen in each simulation and design experiment (how to control variable and collect data). The observation of sediment flow under certain condition used as qualitative evidence to support their position in the debate along with the quantitative data (weight of plastic sand) they collected and analyzed. We prepared a camera and ask students to capture the moments of the instant change in water level and movement of sediments in the reservoir. By controlling each variable, the students could collect both quantitative data regarding the volume plastic sediment and qualitative observation data of how sediment flows (NRC, 2000). After students collect data, the teacher asked them to analyze the data to construct scientific explanation of how sediments flow under certain conditions they controlled.

- **Phase 3**, the second round of community debate: After the science inquiry activity, the students participated in a second round of debate that followed the same format as the first round, a role play community debate In this way, the debate type (role play) would not affect the quality of argumentation before and after the intervention (Simmoneaux, 2001/2008). Each student was assigned to the same represented the same community they had represented in Phase 1. During the debate, participants collectively decided whether they would keep the dam or not based on their discussion of the benefits and consequences of its removal. They decided whether they would keep or revise their positions from the first round debate by considering the scientific evidence gathered from the physical dam model.

Participants

Twenty pre-service secondary school science teachers participated in the study during a secondary school science methodology course at a large university in the Midwest U.S. The pre-service teachers were in their first science methods course in their teacher preparation program. Most of them had scientific backgrounds in biology and chemistry. Only three had a physics background and only one teacher had a background in earth sciences. Thirteen of the teachers were female and seven male, and their ages ranged from 25-30.

Data Collection

Each pre-service teacher was assigned to one of four community debate groups. The participants' arguments during the first and second round debates (before and after the science inquiry activity) were voice recorded and transcribed as the main data source for this study.

Data Analysis

The ultimate goal of the data analysis was to examine both the participants' social negotiation pattern and epistemic understanding of argument during the SSI debates before and after the science inquiry activity. To reach the goal, the analysis of group discussion involved two complementary analytical approaches: (1) the constant comparative methods (Strauss & Corbin, 1990) and (2) the enumerative approach (LeCompte & Preissle, 1993). First, all transcriptions were broken into individual utterances as the unit of analysis. Each utterance represents an idea or opinion contributed to the discussion. An individual's verbal could consist of one or multiple utterances depending on how many ideas were included in one segment of verbal. Two separate sets of coding schemes were developed and applied to the same data set to analyze social negotiation patterns and epistemic understanding of argument. **Figure 1** shows the overall conceptualized framework for data analysis. A detailed description of each analysis process is provided below.

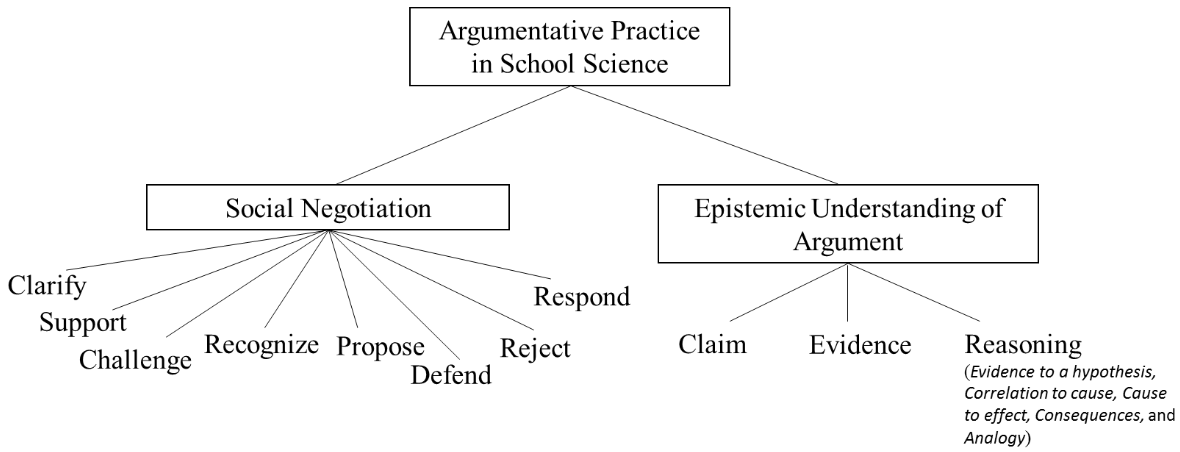

Figure 1. Two dimensions of argumentative practice in school science

Assessing social negotiation pattern and use of evidence

To assess participants' argumentation patterns, we developed an initial set of codes to capture how they construct and critique each other's ideas. First, a coding scheme was developed by open coding (Strauss & Corbin, 1990); this scheme was also informed by previous studies (Chen, Hand, & Park, 2016; Kim & Hand, 2015). Emerging codes were then categorized based on the function of similarities and differences for social negotiation. Eight cods subsequently emerged: clarify, support, challenge, recognize, propose, defend, and reject, and respond.

Table 1. Argumentation coding scheme

Coding (Definition)	Sub-coding (Abbreviation)	Example
Clarify (Clf.) (Give a clear explanation about a situation or example to clarify the individual's idea.)	with evidence (Clf. w/E)	So, in Washington, it's like 80% hydropower. The Columbia River dams supply a ton of power and there are also dams up in other mountain streams and cascades. So this dam isn't supplying power to Seattle…There's an abundance of hydroelectricity.
	without evidence (Clf. wo/E)	Do you see what I'm saying? The consequence of removing the dam is a loss of fresh water. For drinking water.
Support (Spt.) (Any response used by an individual to accept or agree with someone else's ideas.)	with evidence (Spt. w/E)	I have to say on that point again, I know the Northwest Pacific salmon practice is one of the most sustainable in the world. And the problems don't come from the fishing, they come from dams and things like that that reduce the fishing population. So I trust you
	without evidence (Spt. wo/E)	Good point.
Challenge (Clg.) (Any response used by an individual to critique others' ideas or arguments.)	with evidence (Clg. w/E)	The research has shown that the sediment—if they remove the dam in a controlled fashion—will not really play a significant role in dirtying this water. And on a time scale for years, a couple of years, it will no longer be dirty. So Mr. Crown Zellerback's argument isn't too strong.
	without evidence (Clg. wo/E)	How do you transport this?
Recognize (Rcg.) (Acknowledge and realize the existence of factors and variables that could affect the current situation or problem.)	with evidence (Rcg. w/E)	Port Angeles is really hurting right now from the huge recession and a lot of that had to do with the forestry industry going down. So, if this ends up as a negative effect and the fishing industry goes down, there's going to be a lot to pay because these people have already earned less.
	without evidence (Rcg. wo/E)	There are so many sharp turns in those rivers, though.
Propose (Prp.) (Give a new idea, assumption, or explanation to solve a given situational problem.)	with evidence (Prp. w/E)	It [dam] provides clean and cheap energy to the residents. And the graph shows that by removing the dam the costs of energy from smoke stacks or other forms will sky rocket [increase dramatically]. So, we should keep our dam in place because it provides cheap energy.
	without evidence (Prp. wo/E)	So we have to approach this in a way that we can kind of control the effect or we can observe the changes in the effect.

Table 1 (continued). Argumentation coding scheme

Coding (Definition)	Sub-coding (Abbreviation)	Example
Defend (Dfd.) (Provide an alternative idea which is different or conflicts with the individual's ideas; any response used by an individual to persuade others about his/her ideas.)	with evidence (Dfd. w/E)	So basically the graph is not very good data in our groups' opinion when we discussed this. The alternative is not considered; he is the owner of the dam. Nowhere in the article does it mention that there's going to be significant costs to take down this dam.
	without evidence (Dfd. wo/E)	No, we don't want it to stay put. It needs to move downstream. But, we have to kind of prevent it from just flowing at once.
Reject (Rjt.) (Any response used by an individual to disagree with all or part of the speaker's ideas.)	with evidence (Rjt. w/E)	But it won't stay the same. The parts where the woody debris is deposited will be eroded—I mean that's part of how the meandering works is that it continues and it changes. It doesn't stay the same.
	without evidence (Rjt. wo/E)	But we're for more control. Again, there hasn't been research so we don't know what's going to happen so we should be cautious.
Respond (Rsp.) (Give a relevant and meaningful answer to someone's question.)	with evidence (Rsp. w/E)	Yes, but they don't give other forms of energy they use at the dam.
	without evidence (Rsp. wo/E)	Yep, increased biodiversity.

Based on the coding scheme, participants' discourse was analyzed by three researchers to examine the reliability and validity of the analysis methods. To show how the participant teachers engage in social negotiation in order to achieve consensus, we added an appendix that presents how the same group of participants reached the decision differently before and after the science inquiry. In addition to the final coding scheme, we also analyzed participants' utterances based on their use of evidence using two sub-categories: With Evidence (w/E) and Without Evidence (wo/E). We counted the frequency of the participants' discourse based on the coding scheme to discover patterns in their social negotiation. **Table 1** presents the final coding and sub-coding categories (with and without evidence).

Assessing collaborative scientific reasoning patterns

To assess each group's collaborative scientific reasoning patterns, we adopted Walton's (1996) reasoning scheme for an initial analysis. Walton's reasoning scheme is interpreted based on context, subjects, and topics (Nussbaum, 2011). Reasoning scheme such as correlation to cause and cause to effect are more often used in the context of science education than other discipline (Macagno & Konstantinidou, 2013). For example, in a study conducted by

Nussbaum and Edwards (2011), found six reasoning schemes when students engaged in global warming issues. In a similar vein, Duscul (2008) identified nine reasoning schemes in students' presentation of buoyance and floatation, though he collapsed some of the categories because he found that coding them reliably is difficult. In our study related to the issue of dam removal, we applied Walton's reasoning scheme to code all utterances. Five reasoning schemes were identified: evidence to a hypothesis, correlation to cause, cause to effect, consequences, and analogy. However, because the unique context of our study, which was highly related to the students' geological knowledge and to the time and spatial situation of Elwah river, we found that we need to modify the five reasoning scheme. Based on our initial analysis, we found that the scheme 'cause to effect' can be divided into four sub-categories depending on the multiple and linier relationship between cause and effect. We also added two sub-categories to 'analogy' to delineate specific situation of time and space. We altered the terms to highlight the science content involved in the science inquiry activity; correlation to cause→define variable, evidence to hypothesis→deductive, and consequence→Inductive. **Table 2** presents the final coding scheme and sub-coding schemes that were developed depending on the use of evidence in each type of discourse, with examples. To examine the inter-rater reliability of the coding, the two authors independently coded the transcripts. The initial percentage of agreement for social negotiation was 87% and for reasoning patterns was 85%. Any disagreements were discussed and refined until an agreement was reached and the initial coding was adjusted accordingly.

To explicitly unpack the change of social negotiation pattern and epistemic understanding of argument before and after the science inquiry activity, we counted the frequency of the participants' discourse based on the coding scheme to identify a pattern in their scientific reasoning practice as a result of the science inquiry activity (LeCompte and Preissle 1993). With the quantified data, Chi-square goodness-of-fit analysis was employed to examine statistical difference before and after the science inquiry activity. The statistical significance was determined at an alpha level of 0.01 for all tests. Non-significant results were not reported. To understand the change of participants' scientific reasoning pattern after the science inquiry, we also represented participants' discourse in scientific reasoning maps (see **Figures 5** and 6). Utilizing the Cmap tool, which is a frequently adopted software program to construct concept maps, we created participants' scientific reasoning maps with two major constructs: 1) node, to show ideas and concepts, and 2) arrows and lines, to show scientific reasoning patterns between the ideas and concepts. We used different types of lines to present different types of scientific reasoning codes and also put the abbreviation of each reasoning code in the line.

Table 2. Scientific reasoning coding scheme

Reasoning Code (Definition)	Sub-coding (Abbreviation)	Examples
Causal Divided into four sub-coding themes depending on the number of a causal chain (cause – effect) and multiple connections between causes and effects.	Linear - One chain causal relationship (LCo)	We decided we should take down the dam so that our beaches can be revitalized.
	Linear - Multiple chains causal relationship (LCm)	I'm a resident of Port Angeles and my main concern is that I have beachfront property after the dam and since there is no sediment coming down, my beach is eroding. Which is hurting my tourism potential.
	Multiple causes with single effect (MCc)	My other concern is because of the dam the cost of our electricity is cheap so I image I'll be paying more for electricity after it's removed, so you know, I wouldn't like to do. We're also concerned about the availability of fresh drinking water. So once those sediments return to flowing through the whole river—I don't know how that works—but I imagine it'd have to be purified in some way and that would also cost the town and the residents more money.
	Multiple effects are caused by a single cause (MCe)	We advocate the removal of the dam because it will restore spawning grounds and fishing grounds and it will uncover our sacred land.
Analogical (An) Divided into two sub-coding themes depending on the context in which the participants constructed an analogy: 1) time scale and 2) physical/spatial scale.	Compare/time scale (An (T))	I think it's going to take over two years or more to get this through because in the spring it's crazy how the flow is there. And so, I think that their strategy is probably like, "In the summer we don't get any rain up there. Our grass dies. And so, the summer and into the fall, until we get our rains in November, it's a really ideal time to do the first phase."
	Compare/physical and spatial scale (An (P/S))	I think the other thing that would be neat to see is: how big is the salmon compared to this model? You see this water flowing over this sediment and it's super low. But, again this could be something that's still three or four times as deep as the depth and height of the salmon.
Defining Variable (DV) Participants' scientific reasoning, specifically correlational reasoning, to identify relevant variables that expand or limit the realm of evidence.	Define variables that would expand or limit realm of evidence (DV)	We did first three blocks and then two blocks. But, it didn't actually happen that way because the rain was the limiting factor. And so, even though we removed the dam, the river wasn't opened up right away because of the rain.
Deductive (Ded) Participants' reasoning skill of applying general ideas to a specific situation to use as evidence to support their claim.	Trying to apply general idea to specific situation to use as evidence (Ded)	But it won't stay the same. The parts where the woody debris is deposited will be eroded—I mean that's part of how the meandering works is that it continues and it changes. It doesn't stay the same.
Inductive (Ind) Participants' scientific reasoning skill of generalizing examples from a specific situation to a broader context to use as evidence to support their claim.	Trying to generalize examples in specific situation to broader contexts to use as evidence (Ind)	Yeah. But, I feel that eventually the sediments will be gone. Because, based on the models over there, if there's no dam over there and the water keeps flowing for years, then it's just going to be back to normal.

RESULTS

Patterns of Social Negotiation Before and After the Science Inquiry Activity

Based on the analysis of social negotiation before and after the modeling activity, first we developed a data table to present the frequency of each group's utterances under each coding category. We then represented the frequency analysis result in a bar graph format in **Figure 2**. **Figure 2** clearly presents important patterns of social negotiation revealed by the analysis. The results of Chi-square goodness-of-fit test revealed that the observed differences in negotiation patterns before and after science inquiry activity were statistically significant, $X^2(7)=69.904$, $p<.001$.

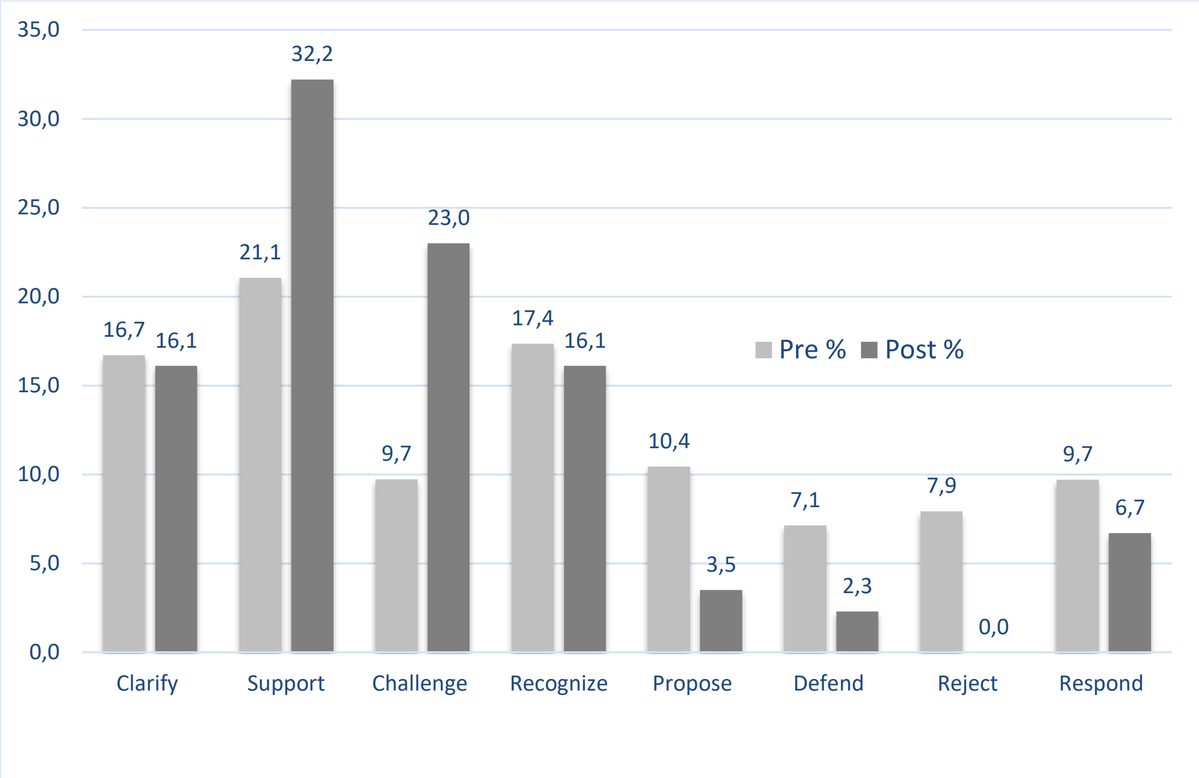

Figure 2. Frequency of utterances revealing social negotiation patterns before (pre) and after (post) the inquiry activity

First, **Figure 2** shows that six of eight social negotiation coding categories contributed to the total discourse about 10% or more before the activity (Clarify [16.7%], Support [21.1%], Challenge [9.7%], Recognize [17.4%], Propose [10.4%], and Respond [9.7%]). In particular, the frequency of utterances in three of these categories did not change much after the activity (less than 30% of its prior frequency) with slightly lower frequency (Clarify [16.7→16.1%], Recognize [17.4→16.1%], and Respond [9.7→6.7%]). This result demonstrates that the social negotiation pattern of these three categories was not affected by the inquiry activity, but mostly because of the nature of debate in the SSI context and/or the specific debating topic: dam removal.

Second, the other five categories show significant change in frequency of utterances (more than 50% of their prior frequency) with either an increase or decrease after the activity. In particular, there are two categories that showed significantly higher frequency after the activity: Challenge (9.7%→23.0%) and Support (21.1%→32.2%). This result indicates that these two categories played a significant role in shaping argument discourse structure after the inquiry activity. On the other hand, the other three categories showed a significant decrease: Propose (10.4%→3.5%), Defend (7.1%→2.3%), Reject (7.9%→0.0%). The results suggest that the science inquiry activity affected the participants' negotiation patterns in such a way that they focused less on proposing, defending, or rejecting ideas related to each community's position, but focused more on challenging and recognizing given information and challenging and supporting each other's idea.

Epistemic Understanding of Argument Before and After the Science Inquiry Activity

Use of Evidence

In this section, we present the analysis results of participant epistemic understanding of argument indicated by the frequency change of their use of evidence-based argument before and after the activity. In addition to the eight social negotiation coding categories, participants' discourse was also analyzed by the sub-categories: w/E and wo/E. **Figure 3** presents the frequency of each coding theme with each sub-category (w/E and wo/E) both before (a) and after (b) the inquiry activity.

First, the overall frequency of evidence-based argument increased significantly after the activity (pre: 24.9%→post: 52.0%). The results of Chi-square goodness-of-fit test confirmed that the observed differences before and after science inquiry activity were statistically significant, $X^2(1)=57.135$, $p<.001$. More than half of the participants' discourse after the activity was categorized as evidence-based (**Table 3**). In particular, this pattern was mostly due to the significant increase of utterances within the w/E subcategory in the four categories of Clarify, Support, Challenge, and Recognize (10.1% of total frequency before the activity) →46.4% of total frequency after the inquiry activity). Compared to this significant frequency increase of utterances within the w/E subcategory, the total frequency of utterances within the wo/E subcategories of these four categories stayed similar or decreased after the activity (54.8% →41.1%). This overall pattern after the activity was most evident in the Clarify category than in other categories.

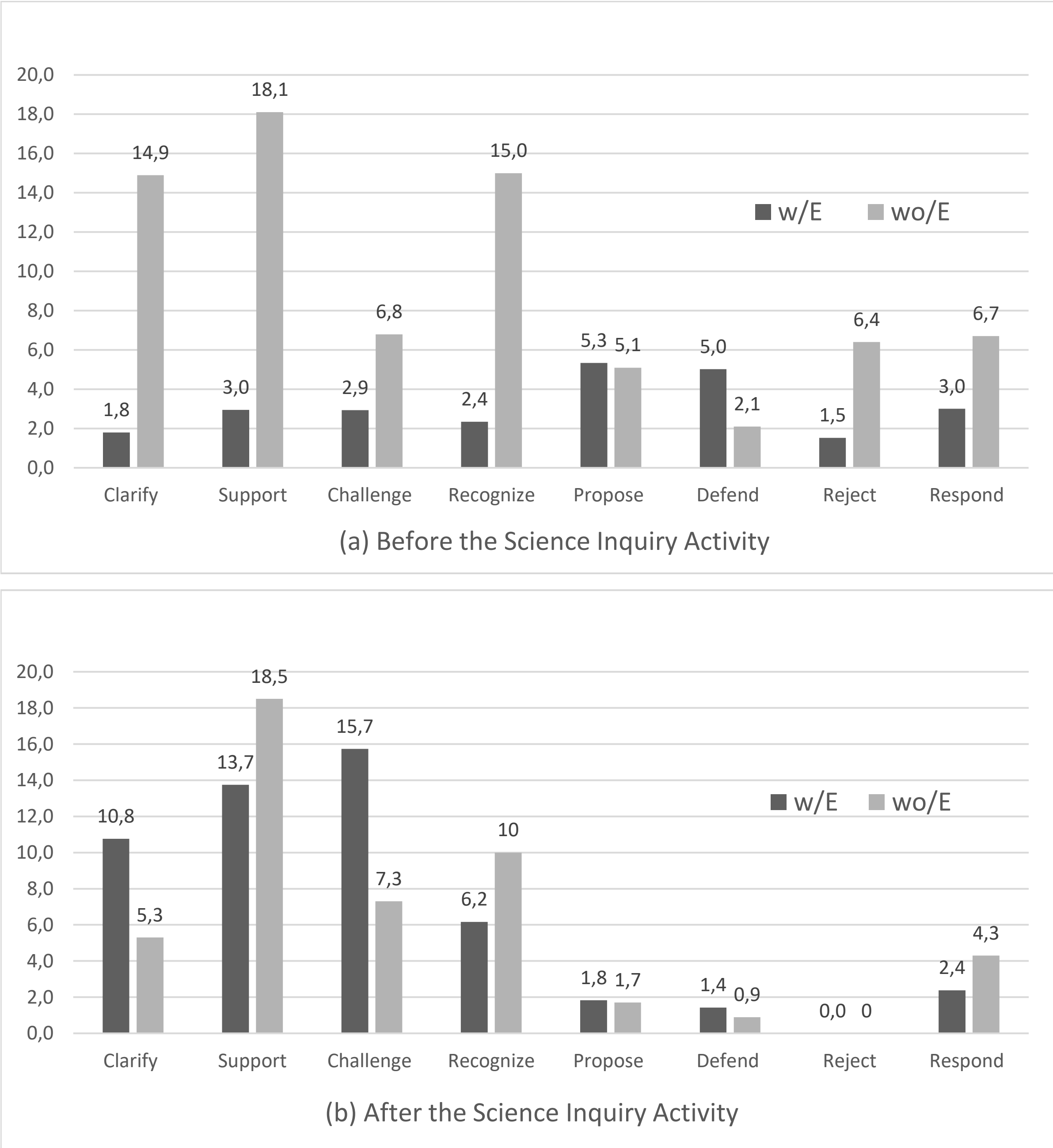

Figure 3. Frequency of utterance of social negotiation pattern in sub-coding themes of With Evidence (w/E) (%) and (b) Without Evidence (wo/E) (%) before (a) and after (b) the inquiry activity

Second, compared to the frequency increase of the first four categories, the overall frequency in the other four categories (Propose, Defend, Reject, and Respond) decreased after the modeling activity (35.1% → 12.5%). The frequency decrease happened in both w/E (14.8% → 5.6%) and wo/E (20.3% → 6.9%) subcategories (see **Table 4** also). However, the ratio between w/E and wo/E in each category stayed similar before and after the activity. This

Table 3. Frequency of argumentative discourses (%) showing opposite patterns between the With Evidence subcategory (increased) and Without Evidence subcategory (decreased) after the physical modeling simulation

						(Frequency %)
Coding Theme	**Sub-coding**	**Pre**	**Post**	**Sub-coding**	**Pre**	**Post**
Clarify	w/E	1.8	10.8	wo/E	14.9	5.3
Support	w/E	3.0	13.7	wo/E	18.1	18.5
Challenge	w/E	2.9	15.7	wo/E	6.8	7.3
Recognize	w/E	2.4	6.2	wo/E	15.0	10.0
	Total	10.1	46.4	Total	54.8	41.1
	Average	2.5	11.6	Average	13.7	10.3

result indicates that the science inquiry activity lowered the overall frequency of these types of social negotiation regardless of its subcategory's frequency of w/E and wo/E. In addition, the frequency decrease of w/E sub-category of Defend (5.0% → 1.4%) was ignored to find a general pattern of this data because its influence in the whole discourse was minimal.

Table 4. Frequency of argumentative discourses (%) that decreased in both With Evidence and Without Evidence subcategories after the science inquiry activity

						(Frequency %)
Coding Theme	**Sub-coding**	**Pre**	**Post**	**Sub-coding**	**Pre**	**Post**
Propose	w/E	5.3	1.8	wo/E	5.1	1.7
Defend	w/E	5.0	1.4	wo/E	2.1	0.9
Reject	w/E	1.5	0.0	wo/E	6.4	0.0
Respond	w/E	3.0	2.4	wo/E	6.7	4.3
	Total	14.8	5.6	Total	20.3	6.9
	Average	3.7	1.4	Average	5.1	1.7

Participants' Scientific Reasoning Before and After the Science Inquiry Activity

Table 5 presents the results of participants' scientific reasoning in the group decision-making process. It shows that Causal Reasoning was the dominant reasoning pattern before the activity (86.6%), but the frequency of this category decreased significantly after the activity (31.5%). After the activity, the frequency of all of the subcategories of the Causal Reasoning also decreased except the subcategory, Multiple Causes with single effect (MCc) (0.8% → 3.6%). Compared to the Causal Reasoning category, the frequencies of the other categories showed opposite results. Analogical, Defining Variable, Deductive, and Inductive Reasoning increased significantly after the science inquiry activity. The results of Chi-square goodness-of-fit test confirmed that the observed difference in reasoning patterns before and after science inquiry activity was statistically significant, $X^2(8)= 21941.580$, $p<.001$.

Table 5. Frequency of collaborative scientific reasoning (%) Before and After the science inquiry activity

			(Frequency %)
Scientific Reasoning	**Sub-category**	**Before (%)**	**After (%)**
Causal Reasoning	LOc	42.1	23.7
	LMc	27.9	3.3
	McC	0.8	3.6
	McE	15.7	1.0
	Sub-total	86.6	31.5
Analogical Reasoning	An/Com/T	0.0	2.0
	An/Com/S	0.0	15.5
Define Variable (IdV)		0.6	10.1
Deductive Reasoning (Ded)		7.0	19.8
Inductive Reasoning (Ind)		5.9	21.1
	Sub-total	13.5	68.4

Figure 4 represents the same results from **Table 5** in a bar graph format to clearly show the change in scientific reasoning patterns before and after the science inquiry activity. First, most of the Causal Reasoning subcategories decreased. Because the increase in the MCc category was minimal, the total frequency of the Causal Reasoning category after the activity decreased from 86.6% to 31.5%. Among the subcategories, Linear Causal reasoning with one chain (LCo) was a dominant causal reasoning type both before and after the activity. However, the frequency of subcategory LCo decreased about 50% after the activity

Figure 4 also shows that the category of Analogical Reasoning in the Physical/Spatial scale and Time scale newly appeared in the participants' reasoning pattern after the activity. This result implies that the nature of the science inquiry using a physical model affected participants' reasoning in making comparisons between the physical and temporal context of the physical model and the real river valleys' environmental context in order to provide sound explanations about the consequences of the dam removal. Particularly, the higher frequency of the subcategory Physical/Spatial scale (15.5%) compared to the Time scale (2.0%) support the idea that participants focused more on comparing and contrasting the physical context of the modeling (e.g., geographical/geological situation of the dam) than temporal context of the modeling (e.g., water speed and sediment flow rate) with the real situation of the dam removal.

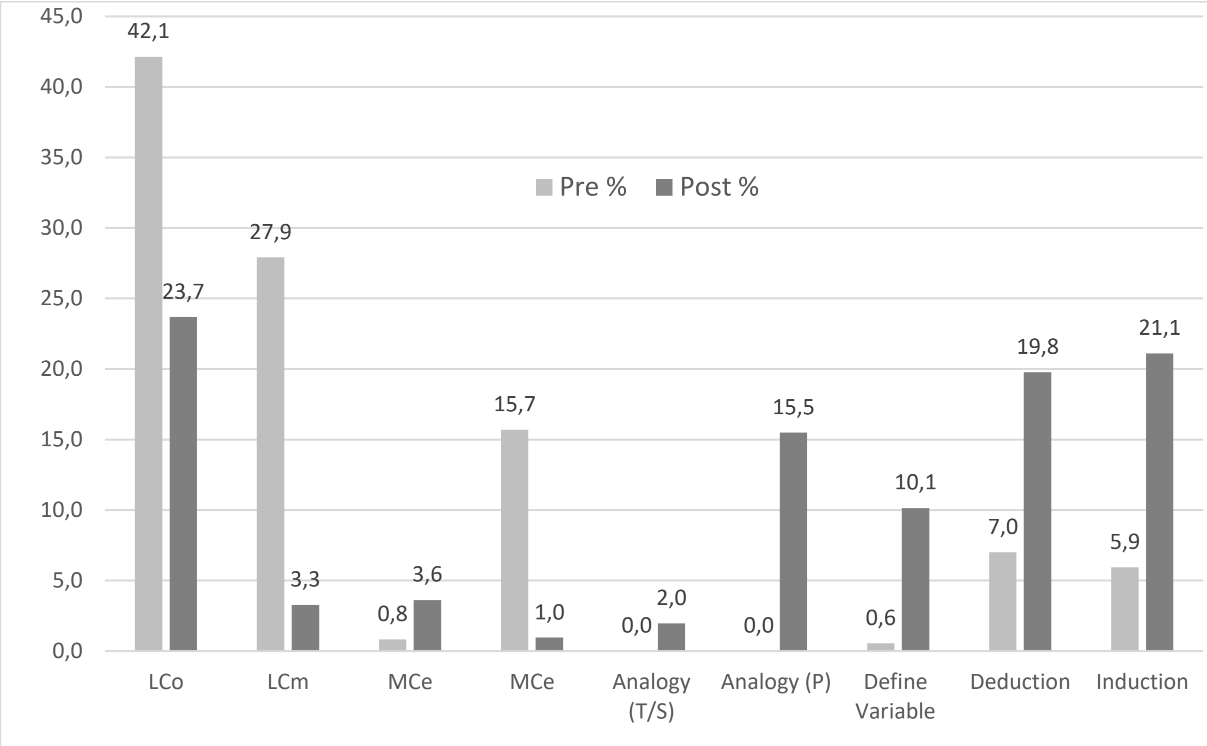

Figure 4. The frequency of scientific reasoning before (Pre %) and after (Post %) the science inquiry activity

In addition, the science inquiry activity promoted participants' scientific reasoning within the category of Define Variable. The increase of the Define Variable category (0.6% →10.1%) suggests that participants' reasoning in this area was reinforced by their experience of testing variables using the physical dam model. That is, after the science inquiry activity, the participating teachers considered more scientific variables that might influence their decision about removing the dam. Before the activity, participants' discourse about the dam removal was mainly focused on one issue: whether it should be removed all at once or piece by piece. This shows that participants were concerned about the sediment flow after removing the dam because of the possibility of destroying fish habitats and the resulting negative effect on the fish industry and local businesses. However, after the activity, the participants recognized multiple variables that could affect sediment flow rate by applying their ideas about the physical model setting to the real geological context. The following excerpt indicates that after the activity, the participants in Group 4 realized new variables they did not mention before the activity and discussed how different variables would affect sediment flow. The places where the participants tried to define new variables are underlined.

> *P2: There's a huge dam of woody debris up there, too. So, depending on how much velocity the water has, it could very well aid that natural environment. But, I'm not a geologist either, so I'm just going by my own personal thoughts on this.*

P3: It could also take the woody debris out of the place.

P2: There are so many crazy turns in those rivers, though.

P1: But it won't stay the same. The parts where the woody debris is deposited will be eroded – I mean that's part of how the meandering works is that it continues and it changes. It doesn't stay the same.

P2: Oh, yeah.

P1: So, I think the main concern with the dam removal is the immediate sediment deposition and the woody debris deposition and how dramatic a change it will cause in the environment once things start leveling out to their new reality, whatever that may be. We'll figure out what to do with it. But, the question is how troublesome that dramatic change will be.

P3: I think it's going to take over two years or more to get this through because in the spring it's crazy how the flow is there. And so, I think that their strategy is probably like, "In the summer we don't get any rain up there. And so, the summer and into the fall, until we get our rains in November, it's a really ideal time to do the first phase, and maybe let that chill out for a while and then maybe do another phase." But, I don't know what their formal thing is right now. It's my hypothesis.

P1: It makes sense because you wouldn't want to be working on a dam during snowmelt or runoff.

The participants discussed different variables such as the elevation ("how much velocity the water has") and location of the sediment in the lake behind the dam based on the physical dam model. In particular, they started to recognize different variables that could affect the sediment flow rate that were not presented in the physical model, such as seasonal precipitation changes ("rain", "snowmelt or runoff"), wood debris, and the shape of the meandering river valley below the dam ("many crazy turns in those rivers").

More importantly, the participants tried to figure out the complex interactions between the multiple variables that could affect sediment flow in the real geological context. For example, the participants tried to understand how both seasonal precipitation changes and location of the sediment in the lake (along the edge or in the center) could affect sediment flow down to the river and fish habitats. In the following excerpt, a participant explains how a possible interaction between two variables (wood debris and size of sediment) would affect the sediment flow after the dam removal:

> *One thing that I think was maybe neglected in the story is that woody debris plays a big role in this. That is blocking something. It is imperative for salmon habitat; if there's no woody debris you're not going to have a calm place for the salmon to lay their eggs. They're just going to keep getting washed away. So, even though they're saying that sometimes the sediment can cover those pools, you're probably in line to ask about the appropriate size sediment. And also, more woody debris that won't get backed up behind it. (A participant in Group 4)*

The experience of testing different variables using the physical dam model seems to help participants to make a more logical conclusion about how to deconstruct the dam with minimal impact on the geological and ecological context near the dam. In addition, the participants realized how difficult it was to decide on one solution opposed to other choices because they realized the consequences of the complex interactions between multiple variables. They thus started to propose new ideas about how to improve the dam model to obtain more reliable data in order to make a sound decision about the dam removal.

The types of scientific reasoning, Deductive Reasoning (7.0→19.8) and Inductive Reasoning (5.9→21.1), also increased after the science inquiry activity. The frequency of these two categories was 40% of the total scientific reasoning after the activity. The increased frequency of Deductive and Inductive Reasoning shows that the science inquiry activity offered a context in which the participants applied general ideas to specific contexts or generalized specific examples to a broader context in order to develop evidence to support their claims or to make sense of the situation. After the inquiry activity, participants tried to predict the relationship between the variables they manipulated by using the physical model and actual sediment flow rate. In doing so, they applied prior scientific knowledge that is specific to the geological and ecological situation of sediment deposit in the lake behind the dam (Deductive Reasoning). For example, the participants tried to deduce the sediment's possible make-up and how its flow could affect the ecosystem. They talked about wood debris as a possible sediment material based on their prior knowledge of sedimentation in a river valley and its environmental impact on the ecosystem near the valley. In addition, the participants also tried to generalize their findings from the physical model to the real river valley's geological context (Inductive Reasoning). For example, they found that the location of the sediment (whether along the edge or in the middle of the lake) and water flow rate affect the sediment flow rate and argued that these factors should affect the real dam removal situation and sediment flow rate along the river valley.

To represent the participants' scientific reasoning patterns described above, we constructed scientific reasoning maps based on the analysis of the results of each group's scientific reasoning patterns. Due to limited space, we only present scientific reasoning maps from Group 3's pre-activity discussion analysis (**Figure 5**) and post-activity discussion analysis (**Figure 6**). Different types of lines in the scientific reasoning map show different types of scientific reasoning patterns between ideas and concepts.

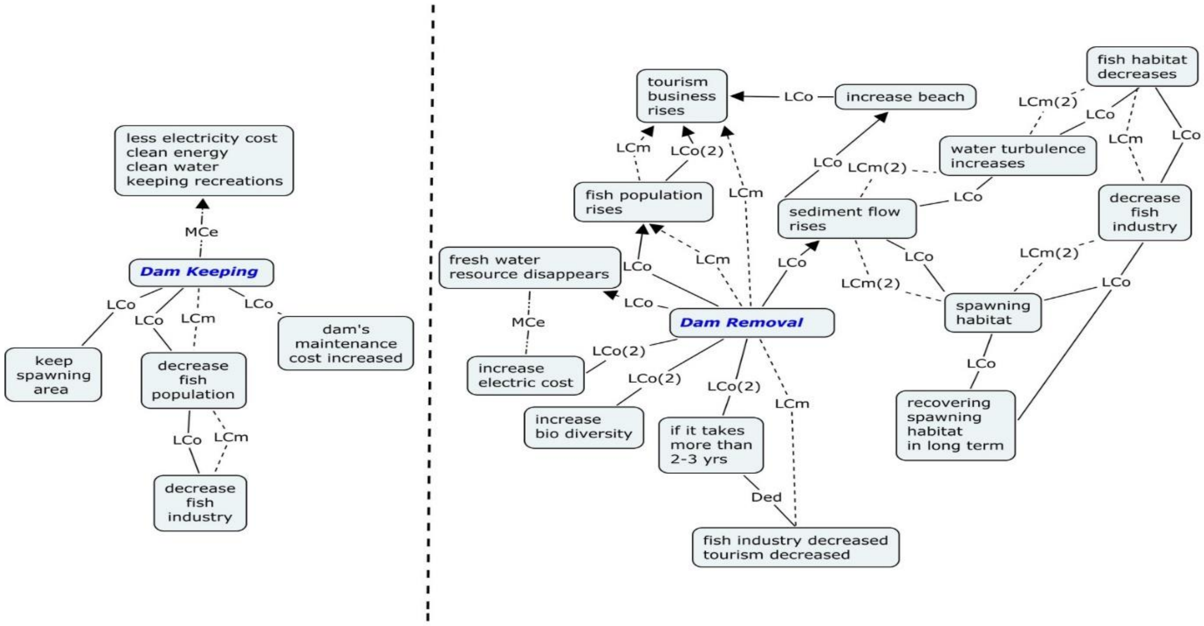

Figure 5. Scientific reasoning map of group 3 before the science inquiry activity [numbers in parentheses with coding scheme abbreviations indicate frequency in the data. For example, a line or arrow with LCo(2) represents that there is a "one chain linear causal reasoning relationship" between the two nodes]

Group 3's pre-activity scientific reasoning map shows that the discussion focused on two distinct topics: Dam Keeping and Dam Removal. The high frequency of linear causal reasoning connected to the central nodes of both Dam Keeping and Dam Removal demonstrate that the participants mainly used Causal Reasoning to determine possible consequences and benefits of both keeping and removing the dam. Throughout the debate before the science inquiry intervention, students' discourse focused on sharing information and making causal relationships to understand the benefits and consequences of the dam removal. However, the reasoning map after the activity (**Figure 6**) has three differences in terms of scientific reasoning patterns: 1) greater and more varied scientific reasoning skills, 2) the frequency of using Analogical, Inductive, and Deductive Reasoning increased significantly, whereas the frequency of Causal Reasoning decreased, 3) more than one variable that could affect the consequences of dam removal was defined either by applying prior knowledge (Analogy) or prediction (Deductive Reasoning).

In addition to the shift in science reasoning patterns, the argumentation topic after the activity shifted from determining benefits and consequences of both dam removal and dam retention to defining only the consequences of dam removal. Specifically, participants were more focused on identifying possible variables that could affect the consequences of dam removal and gathering more information about the real physical and geographical situation of the dam and river valley, and tried to determine the conditions that could influence

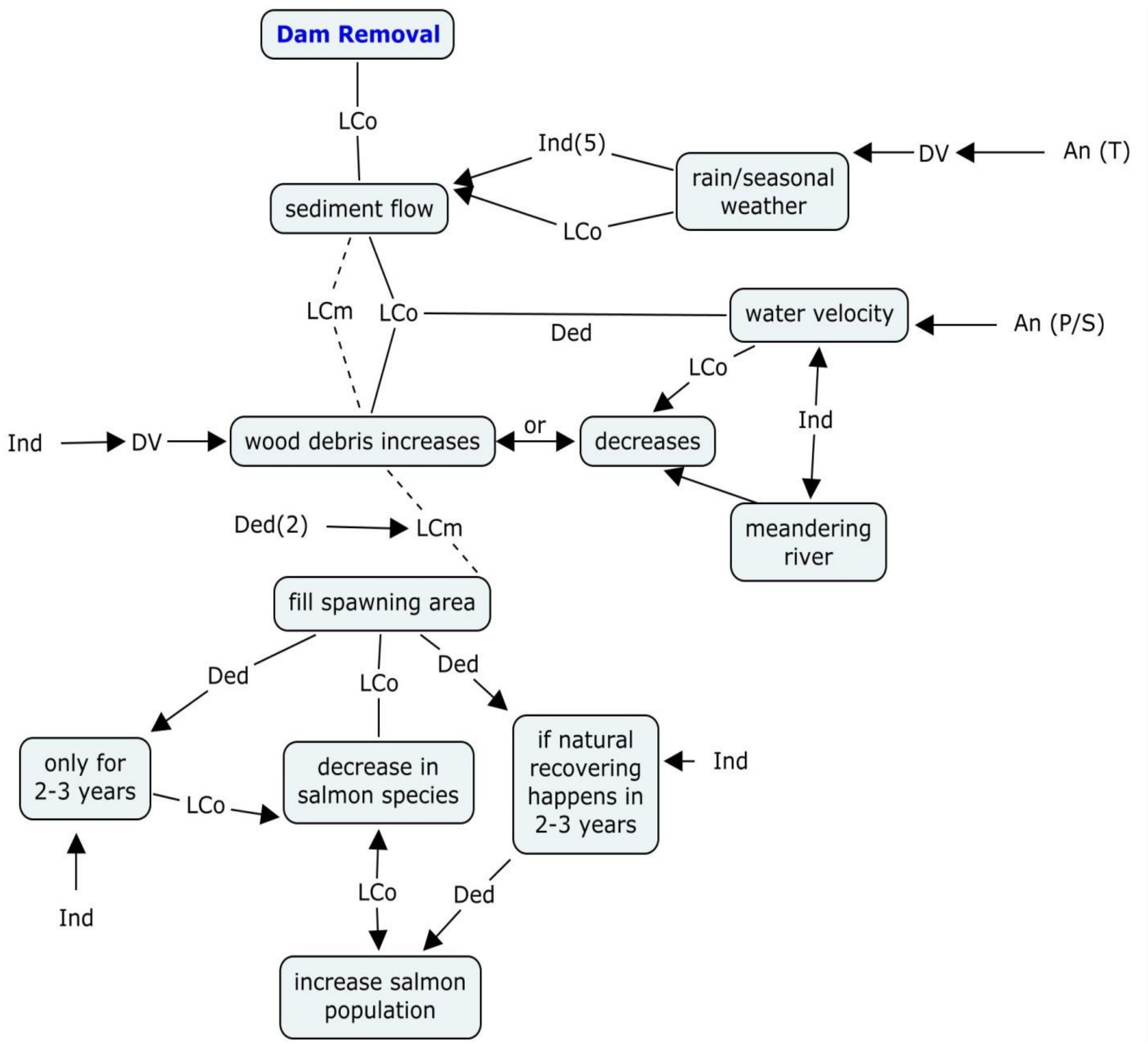

Figure 6. Scientific reasoning map of group 3 after the science inquiry activity

ecosystems and communities around the dam to reduce possible consequences. In other words, the focus of the social negotiation changed from debating about keeping or removing the dam to figuring out the conditions and variables that should be considered to reduce the impact of the dam removal to the ecosystem and nearby communities.

CONCLUSION

The primary purpose of this study was to investigate how incorporating a science inquiry activity affects participants' argument practice. The SSI in this study dealt with the unique environmental situation of the Elwha River Valley, where removing the dam could restore the area's ecology and physical environment. To analyze and interpret participants' epistemic understanding of arguments in a more nuanced and detailed way, we adopted both

Toulmin's structure (1958) and Walton's dialog theory (1996) as our framework. The results showed that a science inquiry activity during SSI debate affected participant's argumentative practice in two dimensions: 1) social negotiation pattern and 2) epistemic understanding of argument (use of evidence during social negotiation and types of scientific reasoning skills).

First, before the science inquiry activity, the major purpose of social negotiation was to make a decision about keeping or removing the dam by defining the benefits and consequences of dam removal based on each community's perspective. When students face an SSI, their emotions, personal beliefs, and values about the issue play an important role in decision-making (e.g., Jho et al., 2014; Patronis, Potari, & Spiliotopoulou, 1999; Sadler & Zeidler, 2005). Similarly, the urgent situation of the need for environmental protection presented in the SSI contributed to the participants' decision of dam removal before the activity. The participants used value oriented reasoning to make their claim to remove the dam and focused on collecting evidence to support it. However, they did not fully account for the consequences of the dam removal when they made the decision. The experience of the science inquiry activity did not change the participants' decision to remove the dam. However, it prompted them to examine their reasoning process critically and recognize that they should have collected more scientific evidence to make sure their decision was better than other choices. In other words, through the experience of authentic science inquiry, participants realized that their decision could not be realistic until they knew the real consequences of the dam removal and that the decision should be supported by a lot more scientific data and evidence. Thus, the inquiry process affected their social negotiation pattern and turned it into more of a collaborative problem solving exercise to reduce the impact of the dam removal. This result was also reflected in the frequency change of the social negotiation coding categories; the significant increase of the frequency of utterances in the Challenge and Support category and the decrease of the frequency of utterances in three other categories: Propose, Defend, and Reject. The frequency change of utterances in these categories implies a change in the social negotiation pattern from a general debate characterized by higher frequency of proposing, defending, and rejecting ideas (Patronis et al., 1999) to more of a discussion for collaborative problem solving that is characterized by a higher frequency of challenging and supporting each other after the activity.

Second, the experience of authentic science inquiry practice enhanced students' understanding of scientific argument. First, students used more evidence-based discourse after the activity: participants' use of evidence-based argument increased after the science inquiry activity (24.9% → 52%). In particular, a significant increase in utterance frequency occurred in the first four social negotiation categories: Clarify, Support, Challenge, Recognize (10.1% → 46.4%). After the activity, social negotiation patterns were dominantly led by these four categories (87.5% of total utterances) and more than half of the utterances in these categories was evidence based. This result also supports the idea that the social negotiation patterns used followed the style of collaborative problem solving more than that of a general debate.

In addition, students tried to define multiple variables and hypothesized about how these variables would interact and what the consequences of dam removal would be. Then they used both collected data and empirical evidence to support their hypothesis and realized that they needed more scientific data to decide whether to remove the dam. The increase of reasoning in the Define Variable category (0.6% → 10.1%) implies that the activity promotes participants' thinking to find correlations between different variables that affect the consequences of dam removal. The increase of Inductive (5.9% → 21.1%) or Deductive Reasoning (7.0% → 19.8%) establish that through the activity, the participants had more opportunity to execute authentic science inquiry practice. They applied their prior knowledge to construct their own hypothesis, used collected data to support their claim, and explained and generalized their hypothesis based on the data they collected. Students' use of evidence and scientific reasoning is a critical indicator to judge the quality of argument (Duschl, 2008; McNeill, 2011; Kuhn, 1996).

On one hand, the results of this study demonstrated that the science inquiry experience positively affects students' disciplinary engagement with scientific argumentation by encouraging them to use a variety of types of scientific reasoning skills and use more evidence-based discourse. On the other hand, students developed system thinking and reasoning skills to collectively analyze, evaluate, and craft rich and complex solution for the issue of dam removal after the science inquiry experience. (Assaraf & Orion, 2010). The reasoning map visually shows that students' group reasoning patterns became non-linear flows and more sophisticated compared to the patterns before science inquiry activity. Students looked at possible connections and associations beyond the information being presented. Warren, Archambault, and Foley (2015) suggested that this kind of system thinking should be emphasized in the classrooms. The most importance is placed on not only the use of argument structure but also adaption of diverse reasoning skills and abilities to design and generate solutions.

IMPLICATIONS

There has been much discussion about the quality of students' argument in the instructional context of using socio-scientific issues (e.g., Fleming, 1986; Kolsto, 2001; Kuhn, 1996; Sadler et al., 2004). These studies indicate that students' lack of ability in evaluating evidence is a critical problem. This study has two implications for future research about the quality of argument in SSI instruction. First, this study suggests a more sophisticated and nuanced analytical framework to examine the quality of argument in an SSI context. Secondly, this study suggests using an explicit instructional approach of authentic inquiry practice as part of the students' decision-making process of an SSI to improve the quality of student argument.

Students' reasoning ability to evaluate evidence and how they use that evidence to support their claim form the essence of epistemic understanding of argument. However, this important component of argument has not been captured well in the SSI debate literature. One of the problems is that most research dealing with socio-scientific issues does not share common or consistent ways of examining the quality of arguments (Acar et al., 2010). Researchers argue that students' reasoning is affected by different personal values (e.g. emotion, intuition, rationality, ethical values, and rationality) that are related to the issue (Sadler & Zeidler, 2005; Zohar & Nemet, 2002). In fact, many SSI instruction researchers understand that the quality of reasoning in SSI context is affected by the personal values. Thus the research in SSI instruction focused particularly on defining what kinds of personal value are used in the reasoning process that is types of different from scientific reasoning; personal value focused reasoning (Zohar & Nemet, 2002), empirical evidence-based reasoning (Kolsto, 2001) informal reasoning (Sadler & Zeidler, 2005) and so on. Different types of reasoning defined in an SSI context is dependent on a specific topic of SSI and are not applicable to understand quality of argument in different SSI contexts.

Some of the researchers such as Osborne et al., (2004) and Zohar and Nemet (2002) considered adopting Toulmin's argument pattern that is more commonly used in scientific argument research (Acar et al., 2010). However, Toulmin's model is not sufficient to identify detailed reasoning patterns that appear in an SSI argument (Hand et al., 2016; Iordanou & Constantinou, 2014; Nussbaum, 2011). By adopting both Toulmin's structure (1958) and Walton's reasoning scheme (1996), our analytical model offers a more comprehensive framework to analyze and evaluate not only the social negotiation patters but also the quality of argument in an SSI context. More importantly, our framework in an SSI context could offer more consistent results about the quality of argument than value focused reasoning that matters by different topics of SSI (Acar et al., 2010).

Second, this study suggests that a carefully designed science inquiry practice during SSI debate could encourage students' reasoning ability to formulate high quality arguments. Researchers have discussed explicit instructional approaches to enhance students' scientific reasoning in an SSI context (e.g., Klosterman, Sadler, & Brown, 2012; Osborne et al., 2004; Zohar & Nemet, 2002). Some of them emphasized the importance of explicit instructional approaches to teach about nature of evidence and opportunities to evaluate different sources of evidence (e.g. Fleming, 1986; Salder et al., 2004). Others argued the importance of choosing topics in which students could be really involved and careful instructional intervention that offers a meaningful context in which students make a personal investment in the solution of the SSI (e.g. Patronis et al., 1999). However, these researches do not share consistent results about the quality of students' argumentation (Acar et al., 2010). It seems like SSI topic is a critical variable to define reasoning types as well as the quality of argument in SSI instruction. In other words, there is no "one size fit all" instructional approach that guarantees the quality of students' argument in an SSI context. Likewise, not every SSI topic has the potential to provide students with an opportunity to engage in a science inquiry as part of the SSI instruction as we suggested in this study. However, incorporating an authentic science inquiry practice in an SSI debate and give students opportunities to engage in their own investigation should be considered as a potential instructional approach that encourage students to formulate higher quality argument in an SSI instruction.

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APPENDICES

Participant Social Negotiation Examples Before and After the Science Inquiry Activity

Before the Activity	After the Activity
P3: The benefit of the dam being there is that the salmon can spawn downstream and the consequence would be the sediment that may stay in the lake. P2: We might see a dip in the population as a result, but eventually in theory it would… P2: I'm not sure there are long term benefits to really keeping it, but there are benefits to not just removing the whole thing. P5: Obviously we need to take into account the effects that will happen if we just dynamite the dam tomorrow. You know, which wouldn't be good for anything. P1: So my question with that is… would it affect the fish directly, because how the dam is removed is going to affect the amount of sediment and turbidity of the water. And whether or not they are sustainable fishers, that's going to affect their fishery directly. P2: And it's going to affect our economy. P1: I'm good, I'm good. P5: So pretty much there's no reason to keep the dam, right? Pretty much, right? P5: But, I think one thing this person would also say is that Port Angeles is really hurting right now from the huge recession and a lot of that had to do with the forestry industry going down. So, if this ends up as a negative effect and the fishing industry goes down, there's going to be a lot of hell to pay because these people have already earned less, so they're not going to be very happy about not having the opportunity to do that. And if you can say that's creating 250 new jobs of restoration, the demographics that's in these jobs aren't going to take these positions. P4: Are there flooding issues in this region? P1: Your research said that if the sediment was going to go down like that then that means more turbidity of the water. That means our fishing goes down initially before the numbers come up, and that means they have less money. P4: Why would the fishing go down?	P1: We did first three and then two (blocks). But, it didn't actually happen that way because the rain was the limiting factor. And so, even though we removed the dam, the river wasn't opened up right away because of the rain. P2: It had limited space to go into. P1: And so then it was above the dam. The water stayed above the dam for a while. And that's different than it would be in the real dam. P3: The water that would need to level off would go out, technically. P4: In real life, how big is this lake, like how long from here to here? P2: Maybe…let's see, it says 5 football fields. P2: One thing that I think was maybe neglected in the story is that woody debris plays a big role in this and that's something that's also being blocked. And also it's imperative for salmon habitat; if there's no woody debris you're not going to have a calm place for the salmon to have their eggs. They're just going to keep getting washed and washed away. So, even though they're saying that sometimes the sediment can cover those pools, you're probably in line to ask the appropriate size sediment. And also, more woody debris that won't get backed up behind it. P1: Eventually, yeah. Definitely. P3: Well, and how much the forest service can actually do something to create more after the rush of water has happened and it's settled a little bit. It needs to set a little bit and then recreate the environment out there, kind of like moving logs in the area and moving them in. Whatever way you can move them into the area of their spawning grounds when it's not spawning season. P2: There's a huge dam of woody debris up there, too. So, depending on how much velocity the water has, it could very well aid that natural environment. But, I'm not a geologist either, so I'm just going by my own personal thoughts on this. P3: It could also take the woody debris out of the place.

P1: Because right away the problem is not going to be solved.
P4: I didn't get to see this. What is this?
P3: At first it's going to kill a bunch of salmon before they learn to spawn further upstream. So the population is going to go down and the ones that can figure out how to go further upstream, above where the dam was…
P4: Survival of the fittest.
P1: What you're going to see is a money issue over there for the fisher, then.
P4: I mean if there are only 4,000 of them right now.
P5: I think so, something like that.
P4: I wonder how much the fishing industry can really harvest if there's only 4,000.
P4: You might have to stop fishing for a while. I wonder if the fishing industry can even fish, because if there are only 4,000…
P5: They may not be able to fish. I mean not really. Not as like an actual business.
P7: We couldn't fish for those fish, but we could fish for other things.
P4: Are there other fish in there?
P7: Well, no. We fish in the river close to the ocean. So yeah, we're pushing them into the ocean, not into the river. So we're fishing for salmon that are out in the ocean.
P4: So your fishing shouldn't be affected too much if you're fishing in the ocean. Other than your numbers going down.
P7: We would feel it, which would affect us because our quotas would be lower.
P5: Salmon from the ocean go to the river to spawn.
P7: Yeah, they have the two environments.

P2: There are so many crazy turns in those rivers, though.
P1: But it won't stay the same. The parts where the woody debris is deposited will be eroded—I mean that's part of how the meandering works is that it continues and it changes. It doesn't stay the same.
P2: Oh, yeah.
P1: So, I think the main concern with the dam removal is the immediate sediment deposition and the woody debris deposition and how dramatic a change it will cause in the environment once things start leveling out to their new reality, whatever that may be. We'll figure out what to do with it. But, the question is how troublesome that dramatic change will be.
P3: I think it's going to take over two years or more to get this through because in the spring it's crazy how the flow is there. And so, I think that their strategy is probably like, "In the summer we don't get any rain up there. And so, the summer and into the fall, until we get our rains in November, it's a really ideal time to do the first phase, and maybe let that chill out for a while and then maybe do another phase." But, I don't know what their formal thing is right now. It's my hypothesis.
P1: It makes sense because you wouldn't want to be working on a dam during snowmelt or runoff.
P2: Yeah.
P1: The problem around here is the change. Not what the change is leading to.

**Note: Above discourse examples are from Group 4' pre and post data*