Assessing In-service Secondary Science Teachers’ Views of Nature of Science and Competence in Understanding Scientific Argumentation about Socio-scientific Issues

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ABSTRACT

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Despite recent efforts to promote scientific argumentation, and to achieve reconceptualized views of the nature of science, including sociocultural accounts, little is known about In-service Secondary Science Teachers’ understanding of the nature of science and cognate aspects. This includes sociocultural aspects and competence in engaging in scientific argumentation about socio-scientific issues. Moreover, there is limited information on how in-service secondary science teachers’ views of the nature of science and their competence in generating scientific argumentation about socio-scientific issues are related, if at all. This also includes their professional skills in applying modern views of scientific argumentation in teaching science.

This study of 13 in-service secondary science teachers used a mixed-methods approach. Descriptive statistics and correlation analysis were utilized to analyze data collected using the Scientific Epistemological Views instrument for evaluating teachers’ views of nature of science from a sociocultural perspective. Responses from the socio-scientific issue item – Global Warming – for evaluating teachers’ competence in understanding scientific argumentation were analyzed using a three-point scale rubric. Correlation analysis between five domains of the Scientific Epistemological Views survey and three components of argumentation and interview data were used to determine the relationship between teachers’ understanding of nature of science and competence in generating scientific argumentation. To future explore the evidence showing that these teachers could learn some of the basic modern ideas about scientific argumentation, I designed an online learning module with pre-post questionnaires assessing
learning gains. Findings of this study highlighted that this group of teachers had an appreciable prior understanding of certain aspects of nature of science and scientific argumentation. The multi-correlation network diagrams generated from analyzing the in-service secondary science teachers’ responses to the Scientific Epistemological Views survey items highlighted the cohesiveness of their group-based percepts regarding the nature of science. It also showed that there were two content themes in the organization of the network diagrams; i.e., 1) the epistemological bases and 2) methodological aspects of the practices of science. Nevertheless, few science teachers were able to generate a cohesive explanation for the set of informed components of scientific argumentation. It was also found that an informed view of the nature of science did not necessarily indicate informed understanding of scientific argumentation. A further correlation analysis (one-tailed, $p < 0.05$) between results of the Scientific Epistemological Views survey and components of scientific argumentation showed that the invented and creative and changing and tentative features of science significantly related to Argument and Counterargument, respectively. Close examination of written responses to the Scientific Epistemological Views survey and socio-scientific issues items, as well as interview data from selected in-service secondary science teachers, further supported the above finding. The changing and tentative (CT) feature of science is found to be significantly and positively related to the total score participants received in the Global Warming questionnaire (one-tailed, $p < 0.05$). Regarding the online learning module about scientific argumentation, pre- and post-surveys of learning outcomes showed good gains from a theoretical perspective after the science teachers completed the online learning module, despite relatively high scores on pre-test items. The learning objectives created by the participants showed that they value students’ use of valid evidence in the process of supporting their claims, though the focus of such process varied.
Further, in their reflective evaluation of the learning module, teachers prefer the addition of workshops that could provide them with practical techniques and related resources for facilitating scientific argumentation within their classrooms.
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CHAPTER 1
INTRODUCTION

Promoting science literacy among ALL ‘science leaners’ is one important goal of science education (American Association for the Advancement of Science, AAAS, 1989). Nature of science (NOS), as one domain of science literacy, emphasizes learners’ understanding of the processes of building a scientific worldview, engaging in scientific inquiry and gaining an understanding of the scientific enterprise (AAAS, 1993). Robust understanding of scientific knowledge and practices, being able to talk about science and making sense of the relationship between science, technology, and society are essential for understanding the nature of science and thus achieving science literacy. Earlier research highlighted the importance of a teachers’ role in fostering students’ understanding of the nature of science (e.g., Lederman, 1992).

Lederman (1992) reviewed literature from the 1960s to 1990s and concluded that “Improvement of teachers’ conceptions appears to have been viewed as a mechanism for helping to ameliorate the problem of inadequate conceptions held by students” (p. 345). From a constructivist position, teachers as guides help students build upon their existing ideas and reconstruct knowledge for a deeper conceptual understanding of science (Erduran & Dagher, 2014). Nevertheless, studies have shown that not only K-12 students but also science teachers have limited understandings of NOS (e.g., Lederman, 1992; Liu, 2009). Science teachers must understand what they are going to teach. Without a sufficient and current view of NOS, science teachers will not be able to adequately address related issues (Lederman, 1992) and promote appropriate attitudes and behaviors (Murcia & Schibeci, 1999).

The rapid development of science and technology has fostered the changes in ways science literacy, and thus the nature of science is defined. Current efforts in science education
focus on expanding the dimensions of science literacy (Liu, 2013) and calling for understanding NOS from a contextualized perspective (Erduran & Dagher, 2014). This further expands the gap between existing teachers’ understanding and the concurrent view of NOS. In instructional practices, various approaches have been recommended to promote deeper and more up-to-date understandings of NOS. The most recent approach depends upon enculturating students into the inquiry processes authentic to the community of scientists (Lave & Wenger, 1991). This would facilitate the unified advance of knowledge, cognition and epistemology of science (Duschl, 2008; Duschl, Schweingruber, & Shouse, 2007; NGSS Lead State, 2013; NRC, 2012). One way to achieve this is to engage students into scientific discursive practices through scientific argumentation (SA), which enables students to gain a deep understanding of scientific knowledge and the science enterprise, and to think critically and reason scientifically (e.g., Driver, Newton, & Osborne, 2000; Kelly & Takao, 2002). Reasoning with peers pushes students to think scientifically and develop new knowledge at an individual level. In this sense, including the diversity and individuality of scientific thinking as part of the sociology of science (Ackermann, 1985) facilitates students’ involvement in practices of science and thus NOS understanding.

There exist calls for using SA about socio-scientific issues (SSIs) (Kolstø, 2001; Zeidler & Keefer, 2003), which are controversial and open-ended problems, as a pedagogy to promote individual students’ critical thinking skills and foster the application of scientific knowledge and moral reasoning in real-world situations. Nevertheless, these efforts have demonstrated limited influences on transforming existing instructional practices. Reasons for this have been attributed to science teachers’ lack of accurate and robust understanding of SA and the requisite skills to implement it into science classrooms.
Meanwhile, the reform (NRC, 2012) in science education demands teachers to bridge the achievement gaps through “Inclusive instructional strategies” (p. 283), approaching science learning in a “Culturally responsive approach” (p. 284) and encouraging diverse scientific discourses. Through these efforts, the committee aimed to promote understanding of the social, cultural and environmental aspects of science among ALL learners despite races, gender, and ethnicities to be scientifically literate citizens. This requires teachers to see students as “Born investigators” and engage students in argumentation as scientists do, and to “Examine, review, and evaluate their own knowledge and ideas and critique those of others” (NRC, 2012, p. 27). In this way, students are expected to understand science within their social lives by discussing and reasoning about science-related issues. To promote such views in modern science classrooms; teachers, especially those who are presently teaching, need to have a current understanding of NOS consisting of sociocultural perspectives.

Additionally, my study and work experiences made me realize the critical roles teachers play in helping students build critical thinking and reasoning and problem-solving skills. I developed an interest in SA because it is a vital practice for shifting the lecture-centered instruction to inquiry and/or practice-based teaching. I wanted to explore the NOS as a result of its importance in promoting science literacy. Nonetheless, the more I read, the more I realize the limitations in existing research regarding how up-to-date in-service science teachers’ (ISSTs) views of NOS are, their competence in understanding SA about socio-scientific issues (SSIs), and how these two dimensions might be related.

**Problem Statement**

Research in science teaching and learning has called upon teachers to use SA for fostering a deep understanding of science content and practices and critical thinking and
reasoning skills and to use SSIs for fostering a better understanding of science and intellectual and moral understanding of science. However, not enough is known regarding teachers’ existing understanding of NOS accounting for sociocultural aspects, and how teachers understand SA about SSIs. There are also limited studies examining the relationship between ISSTs’ understanding of NOS and their competence in understanding scientific argumentation about SSIs. All these are important to investigate as future indicators for promoting students’ concurrent understanding of NOS and fostering SA in science classrooms.

Purpose Statement

Therefore, the purpose of the study was to assess ISSTs’ existing views of NOS and their competence in understanding SA about SSIs. I also aimed to explore how their understanding of NOS relate to their competence in understanding SA within a sociocultural context.

Research Questions

The research questions guided this study were:

1. What characterizes a group of secondary science teachers’ existing understanding of NOS including sociocultural accounts?

2. How competent are a group of secondary science teachers in understanding scientific argumentation about SSIs?

3. What are the characteristics of the relationships between a group of secondary science teachers’ understanding of NOS and their competence in understanding scientific argumentation about SSIs?

4. Is there evidence that a group of secondary science teachers can apply some of the basic modern ideas of scientific argumentation after completing the online module?
Outline of the Dissertation

There are five chapters included in this dissertation: 1) Introduction, 2) Literature Review, 3) Methodology, 4) Results, and 5) Discussion and Conclusion. The first chapter – Introduction – provides background information about this study, problem and purpose statements, and research questions. A review of relevant literature and a conceptual framework serving as the rationales for conducting this study are included in the second chapter. The third chapter contains the methodology utilized to answer the research questions, including research design, participants and setting, data collection, the design of the online learning module, the process of data collection, data analysis, and elements of rigor. Followed by the third chapter, findings of the study are presented sequentially for each research question in chapter four. Finally, the fifth and the last chapter contains the discussion for each research question, followed by a discussion of the contextual factors, consistent cross-cutting results within the study, implications, limitations, and recommendations for future research.
CHAPTER 2

LITERATURE REVIEW

Sociocultural Perspective of Science Education

Sociocultural perspectives of science emphasize both scientific knowledge and the cultural and social context of its development. This determines how science education should be conceptualized and how it should be presented in the curricula – more specifically, how to teach science and how students learn it. As a result, researchers have called for the sociocultural perspective in science education from various perspectives.

This in the first place has to do with how modern science is advanced. Science is not independent of other fields (Lemke, 2001). Modern science, especially, is deeply embedded in social, historical, political and cultural contexts (Kuhn, 1962, 1970; Lemke, 2001). All these stress that science is essentially social; and, moreover, scientific knowledge belongs to the efforts of a community of scientists. “The socio-cultural turn in science education raises the questions of how we understand science, whether we accept its ideology of decontextualized knowledge or locate knowledge in the context of cultural practices” (Mansour & Wegerif, 2013, p. xv.).

It also has to do with how people learn. Vygotsky’s (1978) learning theory claimed that “Human learning presupposes a specific social nature” (p. 88), and stressed the importance of social environments that learners engage in. From an adult perspective, sociocultural theorists support the view that individuals learn through “Situated” social interactions within a community (Lave, 1991) through communications among peers (e.g., Coburn, 2004; Knapp, 2008); and that adults usually take active roles in developing knowledge. This aligns with the nature of human activities. “All human activity functions on multiple scales, from the physiological to the interactional to the organizational to the ecological, and so also on the corresponding time scales.
from the momentary to the biographical, historical, and evolutionary” (Lemke, 2001, p. 297). Thus, emphasizing a sociocultural perspective fosters more effective teaching and learning of science across cultural, religious, and ethical boundaries.

Additionally, this view will shine a light on approaches to narrow the gaps in science education. As Tobin (2012) claimed, adopting a sociocultural framework would help to explain the gaps in science education and USA’s economic incompetence, and to illustrate the “Ongoing and persuasive inequalities” (p. 16) in science education. The current trend of science education aims to build systematical and interdisciplinary science understanding among learners (NRC, 2012). It is necessary for teachers to be aware that: students are not homogeneous; teachers need to include sociocultural perspectives in the curriculum to engage students in learning science and pursue related careers. This highlights the question of who science education is for. All these affirmations concur with the current goals of science literacy, NOS and reform in science education.

**Expanding the Notion of Science Literacy**

One important goal of science education is to prepare ALL learners to be scientifically literate (e.g., AAAS, 1989, 1993). Nevertheless, pathways towards preparing scientifically literate citizens have changed in the last 30 years. One contributing factor is the variations in ways science literacy has been defined. AAAS (1989) proposed new perspectives on scientific literacy and set new expectations: a scientifically literate person was seen as:

One who is aware that science, mathematics, and technology are interdependent human enterprises with strengths and limitations, who understands key concepts and principles of science, who is familiar with the natural world and recognizes both its diversity and
unity, and who uses scientific knowledge and scientific ways of thinking for individual and social purposes. (p. xvii)

This blueprint implicates a robust understanding of science content, science development, and understanding the relationship between science, the natural world, and daily life. This view aligns with Thomas’ and Durant’s (1987) argument about fostering science literacy as it is beneficial from three perspectives: benefits to 1) science, 2) individuals and 3) society as a whole.

Concurrently, 30 years’ collaborative international efforts (e.g., Brown, Reveles, & Kelly, 2005; The Organisation for Economic Co-operation and Development, OECD, 1999) in promoting science literacy have contributed to the idea of situating science literacy into real-world contexts. According to the OECD (1999), essential components of this view include recognizing investigable questions, identifying evidence during investigations, drawing and evaluating conclusions, and demonstrating an understanding of science concepts. All these components focus on bringing problem-solving approaches that are authentic to the community of scientists into daily-life experiences – relating science to society. Norris and Phillips (2003) further call for including the use of language (both reading and writing of science) as part of science literacy.

Nevertheless, Liu (2009) examined the literature and the status of science literacy across the USA and other countries and found that “Achieving science literacy has proven to be no easy task” (p. 304), and that K-16 students hold misconceptions of science concepts (See also Kind, 2004). Through summarizing the flaws among ways approaching science literacy, he discussed issues about joining formal and informal science education and training all professionals to be both science participants and science educators.
Lately, scholars in science education call for a new vision of science literacy (Aikenhead, Orpwood, & Fensham, 2011; Liu, 2013). This is partly because of Roberts’ (2007) two visions of science literacy, which highlight the gap between seeing science as a distinct discipline (Vision I) and stressing its relations to society, technology, and living environments (Vision II). These two visions discouraged students from learning science (e.g., Koballa & Glynn, 2007; Osborne, Simon, & Collins, 2003). The new image aims to address this division through expanding Roberts’ (2007) visions by incorporating action-orientated scientific engagement stressing social, cultural, political and environmental issues (Vision III) (Aikenhead, Orpwood, & Fensham, 2011). Three visions altogether provide a more comprehensive view of science from the orientations of a) pure science emphasizing the scientific content, b) science in relation to society focusing on the science-technology-societal issues and c) science within society highlighting scientific engagement within social, cultural and environmental issues (Liu, 2013). Liu (2013) further argued for the consistency between this expanded notion and current theories of learning, and thus it has the potential to improve formal and informal science education. This notion fits into current science-as-practice and learning-is-doing view – students learn scientific knowledge, understand the relationship of science and society through engaging in social, cultural, political and environmental issues.

**NOS within A Relatively Contemporary Review**

The process of defining NOS involves the development of history, philosophy, and sociology of science (Hodson, 2014; Lederman, 1992). There is still no agreement on a unified definition of NOS over the last 60 years (Lederman, Bartos, & Lederman, 2014); various ways of defining NOS emphasize different aspects followed by various assessment tools (e.g., Chen, 2006; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Tsai & Liu, 2005). For instance,
Chen (2006) focused on the seven elements of NOS as Lederman et al. (2002) stated; but he aimed to address the oversimplification and ambiguity that he detected in the seven elements, and to ascertain ways to explain choices of responses made by respondents to the VOSTS (Views on Science-Technology-Society) questionnaire by Aikenhead, Ryan, and Fleming (1989). Tsai and Liu (2005) designed a Scientific Epistemological Views (SEVs) instrument to assess Taiwanese high school students’ scientific epistemological views with a special emphasis on cultural components in science through a constructivist view. Initially, 35 items were included under five domains, seven in each domain; each item used a five-point Likert scale from 1 (strongly disagree) to 5 (strongly agree). After factor analysis, 19 items (Cronbach Alpha coefficient > 0.55) accounting for 53% of variance were considered as valid representations of the instrument. Follow-up interviews indicated coherency in results reported by this instrument.

NOS is typically defined as the epistemology of science, values, and assumptions coherent with developing scientific knowledge and it stresses how individual beliefs influence the knowledge development of a science discipline (Abd-El-Khalick, 2013; Lederman, 1992, 2004; Lederman & Zeidler, 1987). It describes the nature of scientific knowledge and the underlying process of developing such knowledge. Influenced by the trend in sociocultural perspectives, and following the expanded view of science literacy, science education calls for a new vision of NOS based upon existing research. Among these calls, three main schools of ideas stand out – The Consensus View (CV), Feature of Science (FOS) and Family Resemblance Approach (FRA).

The Consensus View. This school of the idea is led by Lederman and his students, focusing on the teaching and learning of NOS in K-12 education. The most popular “CV,” including seven aspects of NOS, was first summarized by Lederman et al. (2002). This view
consists of seven key aspects: a) tentative nature of scientific knowledge, b) observation, inference and theoretical entities in science, c) theory-laden nature of scientific knowledge, d) creative and imaginative nature of scientific knowledge, e) social and cultural embeddedness of scientific knowledge, f) scientific theories and laws, and g) myth of the scientific methods. Here, the social and cultural influences on scientific knowledge involves two types: a) culture of science which stresses how “Rules of practices and evidence” (p. 508) limit the “Subjectivity through the application of peer review and group consensus” (p. 508) and b) how politics, economics, religion, funding, gender and racial issues influence “The kind of science that is done” (p. 508). Though social and cultural perspective is included, they are seen as two separate dimensions and do not explicit how they influence the development of scientific knowledge.

Based on this “Consensus view”, various empirical studies have been facilitated in science education, along with a variety of questionnaires – View of Nature of Science Questionnaire – in response to the call for standardized NOS assessment instrument (see Lederman et al., 2002). This set of questionnaires is still the most widely used for assessing students’ and teachers’ understanding of NOS.

Within this “Consensus view”, there exist disagreements. Lederman (2007) suggests distinguishing NOS and science inquiry (SI). As he sees it, inquiry refers to the methods and procedures of science, and NOS emphasizes the epistemology of scientific processes and knowledge. Lederman, Bartos, and Lederman (2014) further argue NOS as a cognitive outcome. They think that “NOS and SI, although different, are intimately related and are both important for students to understand” (p. 977) and “Inquiry experiences provide students with fundamental experiences upon which to reflect about aspects of NOS” (p. 977).
Grandy and Duschl (2007) disagree with Lederman (2007) as this distinction ignores the role of models in conceptual understanding of science, oversimplifies the nature of science observation and theory and separates scientific methods from nature of science. This leads to a school of research in epistemology of inquiry (Sandoval, 2005) and epistemological enactment through inquiry (Ford, 2008b). Yacoubian (2012) sees this view as lacking practical implementation, not cohesive in terms of its content and development, and not demonstrating developmental trajectories of how this view develops across grade bands. Therefore, he calls for a critical thinking nature of science framework for guiding NOS lessons.

**Feature of Science (FOS).** Matthews (2012) criticizes the Lederman programme as “Ambiguous.” He thinks it does not include critical historical and philosophical issues like the curricula across several countries did and that it held biases against the “Non-empirical component of science” (Matthews, 2012, p. 15). Matthews (2012, 2016) refuses to call the nature of scientific knowledge as NOS. Instead, he names it as ‘Features of Science’ (FOS) and further expands the list of FOS that can be actually discussed in school science from epistemic and historical aspects. In total, 18 features are included in FOS. Nonetheless, this view is being critiqued as it “Does not present an explicit rationale for selecting these specific features of science and not others” (Erduran & Dagher, 2014, p. 8).

Other critiques of the consensus view mentioned above are consistent with the idea of reconceptualizing nature of science, though the approaches vary. For instance, Clough (2008) suggests expanding the tenets of this consensus view into more explicit statements to encourage discussions of nature of science. Duschl, Erduran, Grandy, and Rudolph (2006) call for broadening the dimensions of NOS. Rather than narrowly focusing on scientific processes and conceptual outcomes, they prescribe a greater focus on the indicative practices that scientists
actually engage in. Other scholars (e.g., Allchin, 2011; Duschl et. al, 2006) propose to shift from ‘consensus view’ to contextualizing it within sociocultural context through various approaches. Allchin (2011) suggests reframing NOS by adding more dimensions that represent the reliability of such practices, from both experimental and social perspectives. These dimensions include the role of funding, motivations, peer review, cognitive biases, fraud, and validation of new methods.

**The Family Resemblance Approach (FRA).** Philosophers of science – Irzik and Nola (2011, 2014) use an alternative approach – Family Resemblance Approach (FRA) – to assess multiple aspects of science including epistemic, cognitive and social perspective. They (2011) criticize the consensus view as: a) describing a narrow view of science, b) portraying “A too monolithic picture of science” (p. 593) as it does not include variations across scientific disciplines and c) lacking “Sufficient systematic unity” and not sufficiently addressing “Certain issues they give rise to” (p. 593). The idea of FRA is developed from the family tree image explaining the similarities and differences among family members. This approach describes the resemblances and differences between different specific science disciplines like a family tree – when two science disciplines have common characteristics, they are seen as pairs and thus included one category. One pair of examples they gave are how Astronomical theories differ from Experimental science.

The initial FRA included four categories: 1) Activities, 2) Aims & Values, 3) Methodologies & Methodological rules, and 4) Products (See Irzik & Nola, 2011). Later on, the researchers expanded it into eight categories through replacing the 4th category as 4) Scientific knowledge and adding three other categories including 5) Professional activities, 6) Scientific
ethos, 7) Social certification and dissemination of scientific knowledge, and 8) Social values (Irzik & Nola, 2014). The detailed domains are listed in Appendix A.

Erduran and Dagher (2014) think of this approach as a holistic and inclusive model; and thus, it is important to science education and policy. They argue that FRA reconceptualizes NOS through “Coordinating the epistemic, cognitive and social aspects of science for the purpose of supporting a more inclusive portrayal of science in science teaching and learning” (p. 3). They also consider the global context of science and stress providing broad, inclusive and equal opportunities and access for all learners to understand science.

**Teaching and learning of NOS.** There are several related, but different, lines of research regarding NOS, for example, 1) evaluating and/ or improving students’ and/ or teachers’ existing understanding of NOS and 2) examining the relationship between students’ and teachers’ understanding of NOS (Lederman, 1992). Sufficient understanding of NOS is necessary for teachers to convey such appropriate understanding to students despite other factors such as classroom management and curricula (Abd-El-Khalick & Lederman, 2000; Lederman, 1992). Efforts aiming to improve science teachers’ understanding of the science enterprise began in the 1960s, and related studies during the following three decades. Abd-El-Khalick and Lederman (2000) indicated that understanding of NOS was not influenced by their content knowledge, science or academic achievement (See Billen & Hasen, 1975; Carey & Stauss, 1969), and not related to cognitive variables like logical thinking (Scharmann, 1988) and gender (Wood, 1972). Concerns regarding the biases and validity issues on standardized instruments that simply categorize teachers’ conceptions of NOS have led Lederman and his team to include interpretative tools within assessment design (e.g., Lederman, 1992; Lederman, Bartos, & Lederman, 2014). Abd-El-Khalick and Lederman (2000) categorize approaches to improve
students’ and teachers’ conceptions into two domains: implicit and explicit ones. The former – implicit one – is characterized by “Instructional sequence in history of science … if it were devoid of any discussion of one or more aspects of NOS” (p. 689); the latter – explicit one – engages learners in “Science-based inquiry activities … if the learners were provided with opportunities to reflect on their experiences from within a conceptual framework that explicates some aspects of NOS” (p. 689). They further argue that knowledge of NOS and knowledge of pedagogy are crucial in the teaching of NOS, and “NOS should be made a pervasive theme throughout science teacher education” (p. 695). Walls (2012) and others (e.g., Akerson & Hanuscin, 2007) advocate for explicit NOS-instructions as inquiry-based strategies that are more aligned with how scientists work.

In instructional practices, various approaches have been recommended to promote deeper and more up-to-date understandings of NOS. Most recent efforts depend upon enculturating students into the inquiry processes authentic to the community of scientists (Lave & Wenger, 1991). One way to achieve this goal is to engage students into scientific discursive practices through argumentation, which has been proven to enable students to gain deep understanding of scientific knowledge and the science enterprise; and to think critically and reason scientifically (e.g., Driver, Newton, & Osborne, 2000; Kelly & Takao, 2002). Participating in reasoning processes with peers pushes students to think scientifically and develop new knowledge.

**Scientific Argumentation in Science Education**

**Arguments, argumentation and scientific argumentation.** It is necessary to differentiate a few related concepts – argument, argumentation, and scientific argumentation (SA), and why the differentiation matters. An argumentation is distinguished from an argument in the sense that *arguments* are mainly for the justification of implied assertions but “Not every
argument is set out in formal defense of an outright assertion” (Toulmin, 2003, p. 12). It emphasizes the practical process of “Judging the soundness, validity, cogency or strength of arguments” (Toulmin, 2003, p. 136). Using the terminology of argumentation instead of argument helps “To distinguish the artifact produced from the process that produces it” (Ryu & Sandoval, 2012, p. 490). Duschl, Schweingruber and Shouse (2007) state that argumentation focuses more on the process of getting out “The relationship between ideas and the evidence” (p. 33) rather than merely taking a position of approving or disapproving; thus, argumentation teases information out of the discussion process. Distinguishing these two concepts contributes to understanding how processes of argumentation influence differences among produced arguments. The final goal of science education is to facilitate learners to evaluate arguments and make judgments without going through the process of argumentation (Ryu & Sandoval, 2012).

The language of argumentation includes words such as theory, claims, observing, discussing, arguments, data, evidence, measurements, rebuttals and so forth. In the process of science learning, the appropriateness of language use is valued (Duschl, 2008; Lemke, 1990; Toulmin, 2003). According to Lemke (1990), knowing how to “Talk science” means knowing ways to “Use this specialized conceptual language in reading and writing, in reasoning and problem solving, and in guiding practical action in the laboratory and in daily life” (p. 1). The language of science, itself, is required to be distinct; but not excluded by its semantics – what its components mean, how they are related grammatically, structurally and discursively and the patterns in discourses and activities (Lemke, 1990).

Scientific argumentation, or SA, refers to the argumentation that is legitimated and authentic to science disciplines, including both spoken and written language. To make argumentation scientific, it is essential to engage in argumentative processes similar to those of
scientists (Manz, 2015). These processes include using the language of science to build, defend, relate, justify and evaluate and finally persuade others to accept your claims (Driver, Newton, & Osborne, 2000; Toulmin, 2003). Toulmin (2003) highlights the importance of criticizing and assessing statements and utterances into specific situations and so do arguments, judgments or predictions. Analyzing language use provides hints to measure the fitness and soundness of arguments (Berland, 2011; Berland & Hammer, 2012; Berland, & McNeill, 2009), as the practice of argumentation is part of the practice of language (Cavagnetto, 2010). Language use in science for building scientific knowledge makes cognitive processes public (Jiménez-Aleixandre & Erduran, 2007). Thus, properly and soundly structured scientific language is of importance in building conceptual structures connecting components of scientific argumentation (Duschl, Schweingruber, & Shouse, 2007) and form a logistically sound discourse (Lemke, 1990) or argument (Toulmin, 2003).

**Engaging in scientific argumentation.** The nature of knowledge is situated in experiences and is social-culturally related (Brown, Collins, & Duiguid, 1989; Driver, Newton, & Osborne, 2000; Lave & Wenger, 1991), and the nature of scientific knowledge is public and a collaborative effort among peers (Ford, 2008a). SA, focusing on the processes of going through the practical and sociocultural perspectives of science to foster student individual development, is supported by research on situated cognition, social-cultural learning, epistemology, psychology, and so forth (Jiménez-Aleixandre & Erduran, 2007).

This is supported by practical studies from different disciplines. Kuhn and Pearsall (2000) analyze argumentation from a developmental and psychological perspective, and thus emphasizes on how frameworks of students’ scientific thinking originate from the starting point, develops and ends with kids’ maturity as “A single continuum” (p. 117) of category claim, event
claim, causal or explanatory claim and explanatory system claim. Garcia-Mila and Anderson (2007) take a similar perspective to analyze the cognitive foundations of argumentation. They further claim that argumentative activities include “Externalized explicit of dialectical activity” (p. 34) in discursive practices and “Internal dialectical coordination between theories, evidence, and methodologies” (p. 35) focusing on scientific reasoning. According to Garcia-Mila and Anderson (2007), the former and the latter initiate from the stands of interpsychological and intrapsychological, respectively; and they share the core processes in psychology. In addition, Manz (2015) suggests from a social-cultural constructivism view that argumentation should build new knowledge on students’ existing resources, support what students know and their ways of knowing, match student epistemic culture and be used in uncertain activities.

Therefore, science classrooms should include SA for its potential contributions to science education (Jiménez-Aleixandre & Erduran, 2007): a) facilitating cognitive and metacognitive reasoning; b) improving communication and critical thinking skills; c) engaging students in the language of science and thus science literacy; d) supporting practices of science, and e) developing advanced epistemology of evaluation. These contributions are supported by evidence from literature from various aspects (e.g., Duschl, Schweingruber, & Shouse, 2007; Ford, 2012; Kuhn & Pearsall, 2000; Manz, 2015; NRC, 2012; Osborne, 2010; Ryu & Sandoval, 2012; Sandoval & Millwood, 2007).

Duschl, Schweingruber, and Shouse (2007) argue that argumentation helps students actively engage in learning practices to acquire new knowledge and strengthen new understandings in the process of extensive argumentation. “Understanding the norms of argumentation can lead students to understand the epistemological bases of scientific practice” (Sandoval & Millwood, 2012, p. 71). This agrees with Ryu and Sandoval’s (2012) and Manz’s
arguments that argumentation support students’ practices of epistemology in science classrooms.

Argumentation is also proved to be important in improving students’ sense-making in science learning (Ford, 2012), critical thinking and reasoning abilities (Kuhn & Pearsall, 2000) and conceptual understandings (Henderson, MacPherson, Osborne, & Wild, 2015; Osborne, 2010). Furthermore, the latest study by Bathgate, Crowell, Schunn, Cannady, and Dorph (2015) indicates that students, who are able to overcome the risks to disagree with alternative ideas in argumentative processes, gain significantly in science content knowledge and that students’ willingness to engage in argumentative discourse mediates the argumentation process and content-knowledge improvements.

Assessments of scientific argumentation. The main components of argumentation are claims, data, evidence, justifications or rebuttals and warrants (Driver, Newton, & Osborne, 2000; Toulmin, 2003). There exist five main frameworks for assessing scientific argumentation according to Sampson and Clark (2008) and each has affordances and limitations. Toulmin’s (2003) Argument Patterns (TAP) examines how learners talk or write in various situations through qualitatively analyzing the structure of argumentation without providing information regarding conceptual changes or highlighting field-dependent features of argumentation. Zohar and Nemet (2002) modified this TAP model. They examined written arguments from the lenses of how multiple justifications are used to support a conclusion and data. Warrants and backings were put into a single category to foster reliability and validity of the argumentation. This model works better in socio-scientific contexts; nevertheless, it provides limited information on how well students align claims with evidence.
The other three frameworks examine the epistemic status of propositions (Kelly & Takao, 2002), conceptual and epistemic quality of arguments (Sandoval, 2003) and hypothetic-deductive validity of arguments (Lawson, 2003), respectively. Kelly and Takao’s (2002) framework is suggested to be used as an analytical tool for understanding the nature of the task and argumentation construction. It focused more on the quality of argumentation. Though with a limited generality, Sandoval’s (2003) framework works well in examining the quality of scientific explanations and epistemology. Lawson’s (2003) framework evaluates the validity of alternative explanations using hypothetico-deductive validity but neglecting the strengths of warrants.

The five models of argumentation have offered values in both research methodologies and instructional practices (Sampson & Clark, 2008); each approach provides information about components and structure characteristics of argumentation (Ford, 2012). The TAP model, as one of the most fundamental structures of argumentation, has guided the development of curricular materials and standards (Ford, 2012). For instance, Erduran (2007) took a methodological perspective to analyze existing studies and found methods such as TAP (Toulmin, 2003) and Zohar’s and Nemet’s (2002) model to build evaluative rubrics for analyzing how evidence are used to justify claims. Osborne, Henderson, MacPherson, Szu, Wild, and Yao (2016) added a dimension of critique to the TAP model. They think that “Such competency is reliant on both knowledge of content, a tacit meta-knowledge of the features of an argument, the ability to distinguish its component elements, and the ability to construct a rebuttal” (p. 826). They argued that this will further contribute to engaging in contextualized scientific argumentation as a domain-specific element. This concurs with existing reforming documents in science education such as the Framework (NRC, 2012) and the NGSS, which considers argumentation and analysis.
as essential parts of science; in this process, students, like scientists, “Examine, review, and evaluate their own knowledge and ideas and critique those of others” (p. 27).

**Factors influencing scientific argumentation.** Research has highlighted a set of factors influencing individuals’ ability or performance on SA. Voss, Blais, Means, Greene, and Ahwesh (1986) investigated informal reasoning via argumentation among adults who attended college, attended college without taking economics, and attended college and took a few economics classes. Three economics questions were given to participants, and data were analyzed through examining argument development, justification, use of qualifiers and other factors. They found that participants who attended college did considerably better than those who did not attend college, despite differences in gender. Also, whether participants had taken economics classes did not seem to influence the quality of arguments.

Voss and Means (1991) reviewed a set of studies (Perkins, 1985; Voss et al., 1986) examining factors influencing the ability of reasoning informally through argumentation, and found that “General ability is a major characteristic of a good reasoner while age (experience) has not been shown to be a potent factor” (p. 343); though their review was not conclusive regarding how an individual’s ability, age (experience) and domain knowledge influence their reasoning (argumentation). “Better reasoners tend to be analytic, flexible, and they are more inclined to use metacognitive mechanisms” (Voss & Means, p. 343). They concluded that skilled reasoners analyze arguments actively, unpack the statement and/or restructure them. Flexibility allows people to “Generate different types of arguments, as by analogy, by definition, by past precedent and the most frequent, by consequence” (p. 344). Skilled reasoners do this through examining one’s position, come up with arguments to oppose that position, and rebut them in an explicit and efficient way. They further “Make goal-related statements about their reasoning,
make comments about their progress, or the lack of thereof, and provide statements of evaluation regarding their performance” (p. 344).

Teacher Learning

Little (1993) summarized educational reforms from five aspects: 1) subject matter teaching (standard, curriculum, and pedagogy), 2) equity among a diverse student population, 3) student assessment, 4) school social organization, and 5) professionalization of teaching. The current reform in science education touches all perspectives.

Webster-Wright (2010) uses professional learning to shift teacher development from delivering traditional professional development activities towards supporting teachers during self-directed professional learning activities. During professional learning, teachers continue to learn and shape their practice from various activities, such as formal programs and interacting with colleagues. She further suggests an authentic professional learning structure, which includes understanding, engagement, interconnection, and openness. Learning opportunities need to be well-structured to have teachers engage as active constructors of knowledge (Abell, 2006). As the world is getting knowledge-centered and technology-based, many scholars have been taking advantage of technology and developing professional learning environments through e-learning (Reiser & Dempsey, 2012). The Internet allows more innovative professional learning approaches, which is necessary during educational reform (Little, 1993). With the Internet, professional learning can be delivered to participants despite time and/or distance.

CONCEPTUAL FRAMEWORK

NOS and SSI

Chang, Chang, and Tseng (2010) reviewed two decades of the literature from 1990 to 2007 and found that NOS and SSIs were gaining attention. Driver et al. (1996) argued that NOS
knowledge fosters an orientation to learn science content, promote interests in science and make informed decisions on SSIs. Zeidler, Sadler, Simmons, and Howes (2005) saw SSIs as “A distinctly more developed pedagogical strategy” (p. 360) for teachers, not simply “A context for learning science” (p. 360). This approach mainly focused on promoting students’ understanding of science-centered issues and how decision-making are influenced by social interaction and discourse highlighting ethical, moral and emotional dimensions. They envisioned SSIs by considering “How controversial scientific issues and dilemmas affect the intellectual growth of individuals in both personal and societal domains” (p. 361).

Kolstø (2001) claimed that many teaching practices lack transforming NOS into everyday decision-making processes. Values, assumptions, and related scientific concepts are embedded in SSIs (e.g., Kolstø, 2001), thus they provided contexts for understanding NOS (Khishfe, 2012a). A similar argument by Abd-El-Khalick (2012) stated that it is important to include controversial NOS issues into an SSI framework, as this will foster a more developmental view of NOS.

Empirical studies have highlighted a close relationship between the two. For example, Sadler et al. (2004) utilized a global warming theme to situate and elicit 84 high-school students’ understanding of NOS and found that students showed understanding of NOS from empiricism, tentativeness, and social embeddedness perspectives. Walker and Zeilder (2007) used the SSI – genetically modified food – through web-based inquiry to promote NOS understanding among ninth to twelfth-grade students. Students demonstrated understanding from tentative, creative, and subjective perspectives of NOS, though they were not successful in using these aspects to debate. Another study by Matkins and Bell (2007) used explicit instruction for promoting 15 pre-service teachers’ view of NOS and global climate change and global warming. After a series of pre-post assessments, they found not only changes among teachers in understanding socio-
scientific issues, but also improvements in understanding NOS from empirical, tentative, creative, subjective and social and cultural influences. In this study, I use SSIs to provide familiar contexts where teachers can provide scientific argumentation.

**NOS and Scientific Argumentation about SSIs**

In terms of the relationship between argumentation and NOS, the evidence is still unclear and dubious (Soysal, 2015). Related studies fall into two lines: 1) engaging in argumentation to foster NOS understanding (Bell & Linn, 2000; McDonald, 2010) and/or epistemological understanding (Sandoval & Millwood, 2008), and 2) fostering NOS understanding for better engagement in argumentation (e.g., Sandoval & Millwood, 2008). The former line is based on the theory that argumentation requires the coordination of claims and evidence (Sandoval & Millwood, 2008) and helps to reconstruct knowledge (Berland & McNeil, 2010).

At the same time, the science-as-practice view emphasizes the ability to link conceptual understandings of natural systems and develop explanations of these real-world phenomena (Duschl, Schweingruber, & Shouse, 2007). This perspective sees the context of scientific practices as real-world phenomena, which is interdisciplinary in nature. SSIs are contextualized within real-world phenomena and can serve as the context for promoting SA (Khishfe, 2012a). Zolar and Nemet (2002) implemented an experimental design investigating whether explicit instruction of argumentation would improve students’ content knowledge and written arguments in the context of a particular controversial socio-scientific issue – gene therapy and genetic cloning. The result was positive. Another study by Osborne, Erduran, and Simmon (2004) demonstrated a similar outcome. They compared student improvement in argumentation within scientific and socio-scientific contexts and found the latter approach more effectively fostered students’ SA.
Khishfe (2012b) conducted a mixed-methods study assessing the relationship between student understanding of NOS and arguments about SSIs without any NOS nor arguments instruction. Two-hundred-nineteen students (11th grade) from five schools in Beirut, Lebanon participated in this study. A survey consisting of scenarios addressing SSIs about genetically modified food and water fluoridation, followed by questions about argumentation and NOS, was distributed. He found that there is a significant relationship between three NOS aspects – subjective, tentative and empirical and three components – argument, counterargument and rebuttal. Qualitative data highlighted the importance of counterarguments and contextualizing SA in SSIs as they provide students with aspects such as exposure, familiarity, personal relevance, and thus helps to explicate their prior knowledge.

However, Khishfe et al.’s most recent study does not indicate this relationship (e.g., Khishfe, Alshaya, BouJaoude, Mansour, & Alrudiyan, 2017). They conducted a mixed-methods study among 74 11th graders from six schools in Saudi Arabia. Participants were purposefully selected and were provided four social-scientific scenarios – global warming, genetically modified food, acid rain, and human cloning. They aimed to examine the relationship of students’ argumentation components including argument, counterargument, and rebuttal, and their understandings of NOS from subjective, tentative and empirical perspectives. They also reported that there are no significant correlations between argument components and NOS aspects, especially among female students. Nevertheless, a positive relationship between SA about SSIs and NOS aspects were found through qualitative data among students who provided well-developed arguments across four SSIs, especially females. Therefore, she calls for more studies examining the relationship between NOS understandings and SA in different contexts and cultures.
Teaching SA explicitly could effectively help to facilitate students’ well-defined understanding of NOS. Studies have shown few teachers were able to lead students effectively with argumentation activities, because of their limited understanding of SA and/or NOS. In this thesis study, I view the competency of understanding SA as “A complex orchestration of construction and critique of claims, warrants and evidence in situations that require scientific knowledge to resolve” (Osborne et al., 2016, p. 826). Moreover, I view teachers’ understanding of NOS from a consensus view as it highlights the most fundamental aspects of the product and developmental process of science disciplines.
CHAPTER 3

METHODOLOGY

The research design section provides a summary of research questions and data sources, as listed below in Table 3.1. It is followed by related background information regarding this group of 13 experienced In-service Secondary Science Teachers (ISSTs) who participated in this study. Data collection part describes the instruments used for evaluating participants’ understanding of the nature of science (NOS) from a sociocultural lens (e.g., Scientific Epistemological Views (SEVs) Survey), and competence in generating scientific argumentation (SA) about socio-scientific issues (SSIs). Followed by reasons for designing the online learning module, process, data analysis and elements of rigor. Some acronyms may show up later in this chapter includes SN (the role of social negotiation), IC (the invented and creative nature of science), TL (the theory-laden exploration), CU (the cultural impacts), and CT (the changing and tentative feature of scientific knowledge).

Research Design

I adopted a mixed-methods approach (Creswell, 2003). It maximizes the strengths, while minimizing the weaknesses, of both quantitative and qualitative techniques; and simultaneously integrates design components to effectively answer research questions. A detailed summary of the research questions and data collection methods are presented below in Table 3.1.
Table 3.1.

Summary of research questions and sources of data

<table>
<thead>
<tr>
<th>Research Questions</th>
<th>Data Source</th>
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<tbody>
<tr>
<td>RQ1</td>
<td>SEVs Instrument (Appendix D)</td>
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<td></td>
<td>Follow-up semi-structured interview (Appendix E)</td>
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<tr>
<td>RQ2</td>
<td>SSIs Item (Appendix F)</td>
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<td></td>
<td>Follow-up semi-structured interview (Appendix G)</td>
</tr>
<tr>
<td>RQ3</td>
<td>Quantitative and qualitative data from RQ2 &amp; RQ1</td>
</tr>
<tr>
<td>RQ4</td>
<td>Pretest Survey (Appendix I) &amp; Posttest Survey (Appendix J)</td>
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<tr>
<td></td>
<td>Follow-up interview (Appendix K)</td>
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</table>

Note. RQ: Research Question.

Participants and Setting

Participants consisted of 13 In-service Secondary Science Teachers (ISSTs) in the northeastern area of the United States, including eight females and five males. Ten of the 13 participants were recruited online through a nonprofit organization offering professional development workshops among science teachers. Although these 10 participants came from the same online community, they did not meet regularly. The other three participants were recruited from a graduate school of education within a private university. These institutions were chosen because they gave me relatively convenient access to ISSTs who likely had sufficient similarity in backgrounds to serve as participants within a focused, small sample study. Given this is the first study of its kind, care was taken to identify a sufficiently bounded sample of participants to
provide initial grounded evidence that may lead to additional studies with participants of a broader background. Participants’ demographic and background information such as gender, ethnicity and teaching experiences were collected (Appendix B) and presented (Appendix C). Detailed information is presented in Table 3.2.

Table 3.2.

Participants’ demographic backgrounds

<table>
<thead>
<tr>
<th>P*</th>
<th>Gender</th>
<th>Age</th>
<th>Eth</th>
<th>Deg*</th>
<th>Major</th>
<th>Cert* &amp; Area (Yes/No)</th>
<th>Grade*</th>
<th>Sub*</th>
<th>Years*</th>
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<tbody>
<tr>
<td>T2</td>
<td>F</td>
<td>31-40</td>
<td>C</td>
<td>M</td>
<td>C</td>
<td>Y, C</td>
<td>9-12</td>
<td>P</td>
<td>11-15</td>
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<tr>
<td>T4</td>
<td>F</td>
<td>≥40</td>
<td>C</td>
<td>D</td>
<td>P</td>
<td>Y, P</td>
<td>5,9-12</td>
<td>P, GS, AE</td>
<td>11-15</td>
</tr>
<tr>
<td>T5</td>
<td>F</td>
<td>31-40</td>
<td>C</td>
<td>M</td>
<td>B</td>
<td>Y, B</td>
<td>9,12</td>
<td>B</td>
<td>11-15</td>
</tr>
<tr>
<td>T6</td>
<td>F</td>
<td>31-40</td>
<td>C</td>
<td>M</td>
<td>Geo</td>
<td>Y, ES</td>
<td>6,8</td>
<td>GS</td>
<td>11-15</td>
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<tr>
<td>T7</td>
<td>M</td>
<td>31-40</td>
<td>H</td>
<td>M</td>
<td>Eco</td>
<td>Y, B</td>
<td>9</td>
<td>B</td>
<td>1-2</td>
</tr>
<tr>
<td>T8</td>
<td>M</td>
<td>25-30</td>
<td>C</td>
<td>M</td>
<td>A</td>
<td>Y, B</td>
<td>6</td>
<td>GS</td>
<td>3-5</td>
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<td>T9</td>
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<td>M</td>
<td>BS &amp; Psy</td>
<td>Y, B</td>
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<td>C, B, ES, GS</td>
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<tr>
<td>T10</td>
<td>M</td>
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<td>C</td>
<td>M</td>
<td>P &amp; Ma</td>
<td>Y, P, Ma</td>
<td>10-12</td>
<td>P, Ma</td>
<td>3-5</td>
</tr>
<tr>
<td>T11</td>
<td>F</td>
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<td>C</td>
<td>M</td>
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<td>T12</td>
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<td>7,8</td>
<td>GS</td>
<td>6-10</td>
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<tr>
<td>T13</td>
<td>F</td>
<td>31-40</td>
<td>A</td>
<td>M</td>
<td>B</td>
<td>Y, B</td>
<td>6,9-12</td>
<td>B, AP En</td>
<td>3-5</td>
</tr>
</tbody>
</table>

Note: P= Participant  
Eth = Ethnicity (C = Caucasian; H = Hispanic; A = African American)  
Deg. = Highest Degree that are obtained or in process (M = Mater; D = Doctor)  
Cert = Certification Area (A = Anthropology; AE = Aerospace Engineering; AP En = AP Environmental; B = Biology; BS = Biological Science; C = Chemistry; CE = Chemical Engineering; CS = Computer Science; ES = Earth Science; Eco = Economics; Geo = Geology; GS = General Science; Mu = Music; Ma = Mathematics; P = Physics; Psy = Psychology)  
Grade = Grades Taught  
Sub = Subjects Taught  
Years = Years of Teaching Experience

Among these teachers, 11 were self-identified as Caucasian, one as African American, and one as Hispanic. At the time of the study, all participants were 25 years of age or older, held valid teaching certificates, and had taught science for at least one year. Regarding their education
background, 11 teachers were pursuing or held a master’s degree, and two were pursuing or held a doctorate in education. Ten teachers received a single subject certificate, out of which five were in Biology, two each in Physics and Earth Science, respectively; and one in Chemistry. The other three teachers were certified to teach more than one science discipline. Additionally, five of these teachers had previously attended workshops related to scientific argumentation (SA). In terms of teaching experience, two science teachers taught for one or two years, and the other 11 teachers taught for more than three years.

Data Collection

Both quantitative and qualitative data were collected from the ISSTs to develop a rich view of four aspects of their understanding of NOS, SA, and related topics: 1) characteristics of their understanding of NOS, 2) competence in understanding SA about SSIs, 3) relationship between their understanding of NOS and competence in generating SA, and 4) evidence indicating ISSTs’ understanding and application of SA. Several sets of data were collected during one academic semester (Spring 2018), including questionnaires, surveys, and follow-up semi-structured interviews. Detailed data collection instruments for answering specific research questions are described below as pertinent to each question.

Research Question 1: What characterizes a group of secondary science teachers’ existing understanding of NOS including sociocultural accounts?

To address this question appropriately, I collected data using the Scientific Epistemological Views (SEVs) Survey (Appendix D) and follow-up semi-structured interviews (Appendix E).

SEVs Instrument. This instrument was developed by Tsai and Liu (2005) for assessing scientific epistemological views with special emphasis on cultural components in science. It
consists of 19 items each on a five-point Likert scale from 1 (strongly disagree) to 5 (strongly agree) (See Appendix D).

Semi-structured Interview. A follow-up semi-structured interview among a purposefully selected sample of five individuals was conducted. The interview questions were used to gain deeper understanding of participants’ views of NOS from a sociocultural lens (See Appendix E).

Research Question 2: How competent are a group of secondary science teachers in understanding scientific argumentation about SSIs?

SSI Item. I used the SSI item – Global Warming (Appendix F) (Khishfe et al., 2017) to evaluate these teachers’ competence in understanding scientific argumentation.

Semi-structured Interview. Follow-up semi-structured interviews (Appendix G) among above five individuals were conducted after participants completed the questionnaire.

Research Question 3: What are the characteristics of the relationships between a group of secondary science teachers’ understanding of NOS and their competence in understanding scientific argumentation about SSIs?

Quantitative and qualitative data collected to address Research Question 1 and Research Question 2 were used to answer this question.

Research Question 4: Is there evidence that a group of secondary science teachers can apply some of the basic modern ideas of scientific argumentation after completing the online module?

Online learning module with pre-post surveys. I designed a learning module (See guidelines in Appendix H) to enhance ISSTs’ professional knowledge of SA from a theoretical perspective. It was delivered after teachers completed the pre-test survey (Appendix I). This instructional package was intended to facilitate a comprehensive understanding of: 1) why pay attention to scientific argumentation? and 2) where does scientific argumentation fits in the most
recent education reform movements? After completing the learning module, participants completed a post-test survey (Appendix J).

*Semi-structured Interview.* A brief follow-up interview (Appendix K) with above five individuals was conducted to gain insights on ISSTs’ perceptions of the learning module.

**Online Learning Module Design**

From my personal experience with professional development workshops and researching existing literature, how SA is defined and its importance to science education were barely focused on in related learning activities among ISSTs, although there exists literature defining SA (e.g., Driver, Newton, & Osborne, 2000; Manz, 2015). Therefore, this online learning module (Appendix H) was designed to help teachers better understand SA from a theoretical perspective. Furthermore, this online learning module followed principles of modern adult learning and digital module design, including having participants self-direct their learning activities and self-evaluate their prior understanding (Appendix I) of SA and learning gains after engaging in the learning module (Appendix J).

Content (as outlined in Appendix H) such as definitions of SA with an example of scientific argumentation, how it relates to science education from four perspectives, and how it fits into the most recent reform in science education, was included in this module. The module and pre-post assessments were delivered along with other questionnaires from middle March to early April of 2018, among ISSTs who had shown interests in participating in this study during the recruiting stage. Though helping ISSTs practically engage in SA-related lesson planning and instructional practices was not the focus of this learning module, ISSTs were expected to be able to visualize how SA could be included in the lesson planning process and, potentially, generate sample learning objectives after completing the learning process (see Appendix J).
**Process**

Only data from the participants who gave consent were utilized for final analysis. Participants were introduced to the purposes of the study and were informed that there were no right and wrong answers to these questions. Participants provided their names, e-mail address, gender, race/ethnicity, age, highest degree held or pursuing, teaching certification, subjects and grade levels they had taught and the duration of teaching at the time of the study (Appendix B).

This study contained two parts: Part I of the study included a set of questionnaires discussed above – the SEVs instrument (Appendix D), the SSI item on *Global Warming* (Appendix F) and the online learning module (Appendix H) with pre-post learning surveys (Appendix I & Appendix J); Part II of the study was the semi-structured follow-up interviews (Appendix E, Appendix G & Appendix K) on teachers’ responses to the first part of the study among five purposefully selected participants. I chose to deliver the informed consent forms for each part of the study using Qualtrics. It required about 90 minutes to complete the first part of the study, namely: Demographic questions about 5 minutes, SEVs instrument about 10 minutes, SSI-item about 30 minutes, one instructional module about 30 minutes, pre-test survey on the online module about 5 minutes and a post-test survey about the online module approximately 10 minutes. After this, Part II of the study was conducted among purposefully selected participants based on the participants’ responses to the SEVs and SSI item, each took 30-45 minutes. All 13 participants consented to participate in both parts of the study and six teachers were selected initially and five were interviewed in the end.

Some challenges encountered in the study included teachers not providing much elaboration of information on the SSI item, or not finishing the designed learning module as expected. The follow-up interviews added extra information to the data collected from the SSI
item. I made the learning module as concise as possible, with a goal of promoting an intensive professional learning experience.

**Data Analysis**

**The SEVs instrument (Appendix D).** Analytical statistics were provided to describe how participants’ understanding of NOS distributed among the Likert scale items. An item correlation network diagram was constructed to show the intercorrelations among the teachers’ NOS perceptions (http://pocketknowledge.tc.columbia.edu/home.php/viewfile/149468 ). This method of analysis provides a composite perspective on the group-based percepts of a sample of respondents. Multiple correlations among all items in a survey are obtained and the relationships are shown in a network diagram where each item is a node, and a connecting linkage between pairs of nodes indicates a correlation between the two nodes (for an example, see Fig. 4.1 in the Results chapter). A multiple correlation was conducted among all 19 Likert Scale items within the SEVs instrument (See Appendix D) using SPSS to gain evidence of r values for the inter-correlation network diagram. When pairwise absolute correlation was at least $|r| = 0.5$ or higher (p-value < 0.05), all 19 items were included to build an inter-correlation network diagram. To make the diagram more discriminative and concise, however, all pairwise correlations that reached at least $|r| = 0.6$ and higher were used to construct the network diagram. Under this selection criterion, there were 13 pairs of correlations that were used with 14 Likert items, all of which were significant at p-value < 0.05.

There were three pairs of correlations with five items (IC_2, IC_3, IC_4, TL_3, and CT_1), that were not connected to the main network diagram (interpreted as satellite, not connected, items). In the end, only nine out of the 14 Likert items served as nodes within the final network diagram, with correlation value inserted above the line connecting a pair of nodes.
The (+) and (-) sign on top of a node indicates whether this node is a regular item or an antipolar item respectively. When there was a group of nodes that formed a discernible assembly relative to the remaining nodes in the network, the assembly of nodes is referred to as a cluster.

**The SSI item (Appendix F).** The SSI - *Global Warming* by Khishfe et al. (2017) was used to evaluate participants’ competence in providing argumentation (See Appendix F). Initial analysis of participants’ responses to the SSI item did not consider the positions that ISSTs took but focused on how coherently they constructed their arguments.

Different question items on this questionnaire served different purposes (See Appendix L) according to Khishfe (2012b). Participants were first asked to make decisions in Question (a) on their position regarding whether they think that your country should have joined the Kyoto Protocol. All 13 ISSTs selected “YES”, which showed that they all thought that their country – U.S. should join the Kyoto Protocol. Questions (b), (c) and (d) evaluated participants’ skills in generating – argument, counterargument, and rebuttals, respectively. Based on these three components, responses to these three questions from participants were classified into three levels – naïve (score 1), intermediary (score 2) and informed (score 3). The rubric (Appendix M) was adapted from the study by Khishfe (2012b). A response was categorized as naïve when there was no reason or an irrelevant or invalid reason was provided. A response was categorized as intermediary when there was only one valid reason provided. A response was categorized as informed when there were two or more valid reasons provided. Such reasons include scientific-based evidence or a scientifically sound fact, report and so forth.

Two researchers analyzed two cases independently and then discussed the grading rubrics and scoring results. Differences in the categorization were discussed until consensus was reached. The rest of the cases were analyzed independently. The inter-rater reliability in the first
round of scoring was 64% as the other inter-rater and I had a disagreement regarding whether an economically sound reason should be considered as a valid scientific reason. After consulting Professor O. Roger Anderson, a senior scientist of natural sciences with extended experience in science learning and science teacher education, we learned that economically sound reasons are also considered scientifically sound, though not from a natural science perspective. After re-examining the responses, the inter-rater reliability was 85%. Furthermore, a correlation analysis was conducted to analyze the relationship between three components of generated SA.

**Semi-structured interviews.** Interviews with purposefully selected participants were carefully analyzed to generate summaries of their views of NOS and competence in understanding SA. To be specific, after converting participants’ responses to antipolar items into normal scales in SEVs survey, the total scores of the CT (*The changing and tentative feature of scientific knowledge*) domain (CT), total scores of SEVs (NOS_T), and total scores of scientific argumentations (SA_T) of the SSI item – *Global Warming*, were compared to select participants for interview. The CT (*changing and tentative*) domain was included as a reference because it better reflects the sociocultural nature of scientific argumentation. In total, five participants were selected for follow up interviews – one participant who scored low and one who scored medium on all three indicators, along with three participants who had a more complex pattern of scores: i.e., scored high on CT domain and high on total score of SEVs, but a medium score on scientific argumentation. These summaries were sorted into various categories, which were compared to the categories generated from the rating rubric.

**Elements of Rigor**

*Research Question 1: What characterizes a group of secondary science teachers’ existing understanding of NOS including sociocultural accounts?*
The SEVs instrument (Appendix D) was validated using both student and teacher data. Moreover, the original authors of the instrument found consistency between students’ and teachers’ scientific epistemological views. As discussed, it can be implemented for investigating a large group of teachers’ SEVs with different dimensions with the possibility to influence students’ learning (Tsai & Liu, 2005). This instrument was meant for assessing social and cultural-dependent nature of science, which aligns with the goal of exploring science teachers’ NOS understanding from a sociocultural stance. Furthermore, data from the SEVs were member-checked (Lincoln & Guba, 1985; Creswell, 2007, 2013) by follow-up, semi-structured interviews (Appendix E), which provided a special emphasis on the cultural components in science that were pertinent to this particular study.

*Research Question 2: How competent are a group of secondary science teachers in understanding scientific argumentation about SSIs?*

Khishfe et al. (2017) have already reported the reliability and validity of the selected SSI-item of Global Warming (Appendix F). In Khishfe et al.’s (2017) study, they analyzed responses related to argumentation skills from argument, counterargument and rebuttal aspects.

Participant-generated scientific arguments about SSIs were analyzed by three researchers, and differences in scoring participants’ responses were discussed until the consensus was reached. Follow-up semi-structured interviews (Appendix G) among purposefully selected individuals were used to gain a deep and rich understanding, and to improve the validity of research interpretations, and they also served the purpose of member-checking (Lincoln & Guba, 1985; Creswell, 2007, 2013) or response validation (Merriam & Tisdell, 2016).
Research Question 3: What are the characteristics of the relationships between a group of secondary science teachers’ understanding of NOS and their competence in understanding scientific argumentation about SSIs?

Existing literature has shown that using socio-scientific issues (SSIs) as contexts for scientific argumentation would facilitate the understanding of the nature of science (NOS) (e.g., Khishfe, 2012b; Zohar & Nemet, 2002), and that a robust NOS understanding would foster the engagement in scientific argumentation (e.g., Berland & McNeil, 2010; McDonald, 2010). Therefore, it is reasonable to expect quantitative and qualitative evidence showing a potential relationship between teachers’ understanding of NOS and competence in generating components of scientific argumentation. Meanwhile, follow up semi-structured interviews included in this study could provide member-checking (Lincoln & Guba, 1985; Creswell, 2007, 2013) or response validation (Merriam & Tisdell, 2016) towards relevant quantitative predictions.

Research Question 4: Is there evidence that a group of secondary science teachers can apply some of the basic modern ideas of scientific argumentation after completing the online module?

Modern methods, like online professional development modules and online self-selected teacher social network (Gray, Lewis, & Tice, 2009), have been recently advocated. Reasons for such advocation include: a) teachers have limited time for professional learning (Dede, Ketelhut, Whitehouse, Breit, & McClosey, 2009); and that b) online learning/ training provides more flexibility and convenience (Clary & Wandersee, 2009). Instead of lectures, these newer learner-centered and research-based models typically include: project-based online learning with instructions, and reflective activities, online case-based instruction for in-service training (Anderson & Baker, 1999), and virtual communities of practice (Keown, 2009). These models
have shown positive learning gains in teacher training practices (Hodgson, Lazarus, & Thurlow, 2011). Therefore, I designed a digital learning module (Appendix H) with the aim of providing an online learning experience where each user can proceed at their own pace and was intended to promote better theoretical understating of SA among ISSTs.
CHAPTER 4

RESULTS

The findings related to each of the four research questions are presented sequentially in this chapter. This group of in-service secondary science teachers’ (ISSTs) understanding of the nature of science (NOS), scientific argumentation (SA) about socio-scientific issues (SSIs), and the relationship between the two provided below corresponding to relevant research questions. In this Chapter, SEVs is an abbreviation for Scientific Epistemological Views, SN for the role of social negotiation, IC for the invented and creative nature of science, TL for the theory-laden exploration, CU for the cultural impacts, and CT for the changing and tentative feature of scientific knowledge.

Research Question 1: What characterizes a group of secondary science teachers’ existing understanding of NOS including sociocultural accounts?

Descriptive statistics. As described in Chapter 3, a SEVs instrument (Appendix D) consisting of 19 five-point Likert scale items with a scale options varying from strongly disagree (score 1) to strongly agree (score 5) was used to evaluate participants’ NOS understanding from a socio-cultural perspective. In order to gain knowledge of the characteristics and trends of teachers’ responses to all items within the SEVs instrument, the frequency of responses to the options in each item are presented in Table 4.1. In this table, to make the data more concise, some responses were combined into a single category. The frequency of responses to “strongly disagree and disagree” were combined into one category as disagree (D). For responses to the option “neither agree or disagree” the data are listed as neutral (N). Responses to “agree and strongly agree” were combined as agree (A).
Table 4.1.

*Frequencies of agreements on individual SEVs items*

<table>
<thead>
<tr>
<th>Items</th>
<th>Items</th>
<th>D</th>
<th>N</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>The role of social negotiation (SN)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SN_1. New scientific knowledge acquires its credibility through the recognition by many scientists in the field.</td>
<td>D</td>
<td>0</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>SN_2. Scientists share some agreed perspectives and ways of conducting research.</td>
<td>D</td>
<td>0</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td>SN_3. The discussion, debates, and result sharing in science community is one major factor facilitating the growth of scientific knowledge.</td>
<td>D</td>
<td>0</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td>SN_4. Valid scientific knowledge requires the acknowledgement of scientists in relevant fields.</td>
<td>D</td>
<td>2</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>SN_5. Contemporary scientists have agreed upon an acceptable set of standards with which to evaluate scientific findings.</td>
<td>D</td>
<td>1</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>SN_6. Through the discussion and debates among scientists, the scientific theories become better.</td>
<td>D</td>
<td>0</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td><strong>The invented and creative nature of science (IC)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IC_1. Scientists’ intuition plays an important role in the development of science.</td>
<td>D</td>
<td>0</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>IC_2. Some accepted scientific knowledge comes from human’s dreams and hunches.</td>
<td>D</td>
<td>5</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>IC_3. The development of scientific theories requires scientists’ imagination and creativity.</td>
<td>D</td>
<td>1</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>IC_4. Creativity is important for the growth of scientific knowledge.</td>
<td>D</td>
<td>0</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td><strong>The theory-laden exploration (TL)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TL_1. Scientists can make totally objective observations, which are not influenced by other factors. *</td>
<td>D</td>
<td>9</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>TL_2. Scientists’ research activities will be affected by their existing theories.</td>
<td>D</td>
<td>0</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>TL_3. The theories scientists hold do not have effects on the process of their exploration in science. *</td>
<td>D</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>The cultural impacts (CU)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CU_1. People from different cultural groups have the same method of interpreting natural phenomena. *</td>
<td>D</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>CU_2. Scientific knowledge is the same in various cultures. *</td>
<td>D</td>
<td>7</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>CU_3. Different cultural groups have different ways of gaining knowledge about nature.</td>
<td>D</td>
<td>0</td>
<td>0</td>
<td>13</td>
</tr>
</tbody>
</table>

(continued)
Note. *Presented in an empiricist-aligned or positivist-oriented perspective. These items are antipolar, which means that a disagree indicates informed expected understanding of the provided information. D: Disagree, N: Neutral, A: Agree.

Based on the data in Table 4.1, teachers’ understandings of NOS were relatively coherent across five domains; that is, the frequencies tended to be distributed largely in either the disagree (D) options for antipolar items, or agree (A) options for non-antipolar items. For instance, in the first domain, teachers were asked about their understanding of the SN (*the role of social negotiation*) domain. The item SN_1 asked whether new scientific knowledge gains its credibility through the recognition of the community of scientists in the field, 10 teachers (77%) agreed or strongly agreed with the statement, whereas none responded with strongly disagree nor disagree, and three teachers (23%) chose neutral. This highlights that most of the sampled teachers think the credibility of new scientific knowledge requires the recognition of many scientists in that field. By comparison, the first item (CT_1) within the domain of *the changing and tentative feature of scientific knowledge* (CT) asked teachers if they thought the development of science knowledge often involves the change of concepts, one teacher (8%) chose a response categorized as D, two teachers (15%) chose neutral, and 10 teachers (77%) agreed or strongly agreed. This indicates that most teachers think change of concepts is part of how science knowledge develops.

Table 4.1. (continued)

<table>
<thead>
<tr>
<th>Items</th>
<th>D</th>
<th>N</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>The changing and tentative feature of scientific knowledge (CT)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT_1. The development of science knowledge often involves the change of concepts.</td>
<td>1</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>CT_2. Contemporary scientific knowledge provides tentative explanations for natural phenomena.</td>
<td>2</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>CT_3. Currently accepted science knowledge may be changed or totally discarded in the future.</td>
<td>0</td>
<td>0</td>
<td>13</td>
</tr>
</tbody>
</table>

Note. *Presented in an empiricist-aligned or positivist-oriented perspective. These items are antipolar, which means that a disagree indicates informed expected understanding of the provided information. D: Disagree, N: Neutral, A: Agree.*
There are seven items where all 13 teachers chose agree or strongly agree. These seven items were distributed within all five domains. Three items were from the SN domain. This meant that all participants agreed or strongly agreed that scientists do share some agreed perspectives and ways of conducting research (SN_2), “The discussion, debates, and result sharing in the science community is one major factor facilitating the growth of scientific knowledge” (SN_3), and that the scientific theories get better through the discussion and debates among scientists (SN_6). Furthermore, there was one item from each of the following domains: (1) the invented and creative nature of science (IC) domain, (2) the theory-laden exploration (TL) domain, (3) the cultural impacts (CU) domain, and (4) the changing and tentative feature of scientific knowledge (CT) domain. Six out of these seven items (SN_2, SN_3, SN_6, IC_4, CU_3, and CT_3) are non-antipolar items, and none of the respondents chose strongly disagree, disagree, or neutral; all 13 teachers strongly agreed or agreed with this statement. Whereas, on the antipolar item – TL_3 stating that “The theories scientists hold do not have effects on the process of their exploration in science”, all 13 either strongly disagreed or disagreed with it. This shows that all teachers think that to some extent, the theories scientists hold do influence the science exploration processes.

There are eight items where teachers’ responses varied and fell into all three categories. On the item IC_3, asking teachers whether some accepted scientific knowledge comes from human’s dreams and hunches, five teachers strongly disagreed or disagreed, two (15%) chose neutral and six agreed or strongly agreed. This means about 38% of the teachers think scientific knowledge might come from people’s dreams or hunches and about 46% do not think so. In the antipolar item CU_2 describing that scientific knowledge is the same in various cultures, seven strongly disagreed or disagreed, three were neutral and three agreed or strongly agreed with the
statement. Seven teachers (54%) agreed that scientific knowledge is different in various cultures and three teachers (23%) agreed that scientific knowledge stays the same across cultures.

Overall, the composite results show that teachers’ responses were more toward agree or strongly agree with regular items and disagree or strongly disagree with the antipolar items. This indicates that most of the respondents were well informed about the socio-cultural aspects of NOS. Nevertheless, teachers’ responses distributed widely on two items: IC_2 (*Some accepted scientific knowledge comes from human’s dreams and hunches*) and the antipolar item – CU_2 (*Scientific knowledge is the same in various cultures*). This shows that teachers’ understanding of these two items varied more than for other items.

**Likert inter-correlation network diagram.** As mentioned above, multiple correlation among all 19 Likert Scale items within the SEVs instrument were used to construct the inter-correlation network diagram (Figure 4.1). When pairwise absolute correlation was at least $|r| = 0.5$ or larger, all 19 items had correlation values within this range. However, only nine of the items had more than one connection with another item (thus forming a node in the network) and were included to build an inter-correlation network diagram as explained in the Methods (Chapter 3). The (+) and (-) sign placed above a node indicates whether this node is a normal, direct polarity, item or an antipolar item, respectively.

There are nine nodes with 10 linkages (Figure 4.1). The inserted paired correlation next to each link ranged from 0.6 to 0.9, with three negative values ($r = -0.6, r = -0.6$ and $r = -0.7$). There are four major nodes (those with the most linkages) namely: CU_1 with four linkages, and SN_1, SN_4 and SN_5 each with three linkages. Three nodes only have one linkage to a paired node and are linked to the periphery of the network. SN_2 is only linked to CU_1, CT_2 is only
linked to CT_3, and CU_3 is only linked to CU_1. Each of these three nodes are categorized as a “peripheral node.”

Figure 4.1. SEVs item inter-correlation network diagram

The overall ratio of linkages to nodes is 10/4 = 2.5. For an intercorrelation network with nine nodes, the maximum possible linkages geometrically that can be constructed (where all possible linkages are made) is 36 or four per node. If all nodes were linked to the maximum, we designate it as saturated. The ratio of the actual number of linkages to the maximum converted to a percent is referred to as the percent saturation. In this case, the percent saturation is (10/36) * 100 = 28%.

Furthermore, a visual inspection of the intercorrelation network suggests that there are two clusters of nodes, identified by the density of linkages that connect them. The cluster to the left consists of five nodes, including CT_2, CT_3, CU_3, SN_2, CU_1. This cluster is less densely linked (less connected to one another), with a mean ratio of internal to nodes of 4/5 = 0.8. The right cluster has four nodes (TL_1, SN_4, SN_5 and SN_1), and are more densely linked (more connected to one another) with a total of five internal linkages for a ratio of 5/4 = 1.3. Also, SN_1 serves as an anchoring node linking the two clusters by the single linkage to
 CU_1. The left cluster of the nodes highlights the epistemology of science including cultural interpretations, and the right cluster emphasizes the methodology of science. This shows that the ideas included in each cluster of nodes are highly related, thematically. This also means that participants all responded in a similar way to each cluster of ideas. In addition to having greater density of linkages, the right-hand cluster of nodes has higher correlation values (mean r = 0.7) compared to the left-hand cluster (mean r = 0.63).

In the left-hand cluster, there are three negative correlations on the linkages from the node CU_1 (“Different cultures interpret phenomena in a same way”); these negative values indicate this group of participants see this item as inversely related to the other three, highlighting a congruent, but inverse, perception in how each pair of items is cognitively perceived by the group. If one item of a pair is rated highly toward “agree,” while the other tends to be rated lower toward “disagree,” this indicates an inverse relationship between the pairs involved. For instance, CU_1 and CU_3 reasonably are negatively correlated, because if the respondent agrees with CU_3 that “Different cultures gain knowledge differently,” then she/ he should not agree with CU_1 that “Different cultures interpret phenomena is a same way;” otherwise, it is a logically inconsistent pair of claims. CU_1 and CT_3 are also negatively correlated. It tells us that if the group of respondents agree with CT_3 that “Current knowledge may be changed or discarded,” then logically they should not agree with CU_1 that “Different cultures interpret phenomena is a same way,” due to the premise that if scientists from all cultures interpret phenomena in the same way, current scientific knowledge is less likely to change. Regarding the negatively correlated pair of CU_1 – “Different cultures interpret phenomena is a same way” and SN_2 – “Scientists agree on some research methods”, it is clear that logically if a group of respondents properly disagrees with CU_1, they should, however,
agree with SN_2, because the basis for scientific inquiry is that some scientific methods are shared by scientists among all cultural groups. As the CU_1 node is one of the major nodes in the left cluster, such negative values overall indicate a significant cognitive cohesiveness (though inversely related) within the group regarding how they perceive the relationship between CU_1 and other three items.

In the right-hand cluster, there is an interesting interconnected triad (TL_1, SN_5, and SN_4) with positive, pairwise correlations. SN_4 “Agreement among scientists validate scientific knowledge” and SN_5 “Agreed standards to evaluate scientific findings” has a very strong correlation (r = 0.9), which is logically reasonable as they both deal with “Standards” in a consistent way. Nevertheless, TL_1 is antipolar, and yet is positively correlated with the other two (SN_4 and SN_5). This means that if participants disagree with TL_1 that “Scientists are totally objective”, they agree with SN_4 that “The agreement among scientists validates scientific knowledge.” Likewise, there is a positive relationship between TL_1 and SN_5 that “There is a set of agreed standards to evaluate scientific findings.” For some reason, the group of respondents see these in a logically similar structural way, even though TL_1 is antipolar – apparently, the topics of “Standards,” “Validation,” and “Objectivity” are in some way cognitively interrelated, but it may be a very subtle and/or deep semantic set of relationships. Such potentially complex relationships often can be better understood if interviews are used as soon as possible to seek clarifications from the participating respondents. This assumes some of these percepts are amenable to metacognition and deep introspective analysis by the respondents. Alternatively, they may represent latent perceptual tendencies, not easily accessed verbally, that require much deeper clinical analysis, if at all possible, to understand.
Summary. In summary, participants agreed or strongly agreed with 15 regular SEVs items and disagreed or strongly disagreed with these four antipolar items. The network diagram consists of two main clusters of nodes, which highlights the cohesiveness of how this group of participants perceived the epistemology and methodology perspectives of science, respectively, including interesting aspects of the relationships among regular and antipolar items.

Research Question 2: How competent are a group of secondary science teachers in understanding scientific argumentation about SSIs?

As I have mentioned in the Methods section (Chapter 3), ISSTs’ responses to three out of seven questions included in the SSI item – Global Warming (Appendix F) were coded according to the rubric (Appendix M). All 13 participants selected “Agree” as a response to the question (a) “Do you think that your country should have joined the Kyoto Protocol?” They agree that their country (U.S.) should be legally responsible for limiting greenhouse gas emissions and keep it stable, though their levels of understanding of these three domains varied. Question (b) states: “Do you think that your country should agree to be legally responsible for limiting greenhouse gas emissions and keeping it stable? Explain and justify your decision.” It asked the respondent to generate an argument with valid reasons. Question (c) states that: “Another scientist, Professor Ponso, disagrees with your decision. How could he explain his position to illustrate the reasons supporting it and convince you?” This question asked the participants to generate a counterargument from another person’s point of view. And question (d) is: “What would you reply to Professor Ponso to explain that your decision is right?” This was included to ask participants to provide a rebuttal that further supports their own arguments.
**Descriptive statistics.** Frequencies of 13 ISSTs’ generated arguments, counterarguments, and rebuttals were tabulated for occurrences within each of the three categories: Naïve (Score = 1), Intermediary (Score = 2) and Informed (Score = 3), as reported in Table 4.2.

In terms of generating an argument, 12 out of the 13 ISSTs were able to provide one or more valid reasons to justify their arguments, and thus received a score of 2 or 3 (Row 1, Table 4.2). With respect to the entry “Counterargument” (Row 2, Table 4.2), four out of 13 teachers received a score of 1, another five received a score of 2 and four received a score of 3. In other words, nine participants generated counterarguments with no invalid or irrelevant justification. Or at the most, one valid reason. This indicates that most of the participants hold naïve or intermediary understanding of counterargument. The data for “Rebuttal” (Row 3, Table 4.2), shows that seven participants either did not provide a valid or relevant reason, or provided only one scientifically sound reason and received a score of 1 or 2, respectively. This indicates that these participants held naïve or intermediary understanding of the meaning of rebuttal.

Table 4.2.

| Frequencies of participants’ understandings of argumentation components |
|------------------|------------------|------------------|
|                  | Naïve (Score 1)  | Intermediary (Score 2) | Informed (Score 3) |
| 1. Argument (n=13) | 1                | 5                | 7                 |
| 2. Counterargument (n=13) | 4                | 5                | 4                 |
| 2. Rebuttal (n=13) | 4                | 3                | 6                 |

The frequencies listed in Table 4.2 are presented more concisely and visually in Figure 4.2. The number at the top of each bar represents the frequency of a score in each component of SA.
Table 4.2 shows that slightly over half \((7/13 = 54\%)\) of ISSTs were able to provide an informed argument with two or more valid reasons, compared to 31\% \((4/13)\) for generating counterarguments and 47\% \((6/13)\) for generating rebuttals. This means that very few participants were able to generate a set of arguments, counterarguments and rebuttals with two or more valid reasons. Also, 38\% \((5/13)\) of respondents were able to provide an argument or counterargument with one valid reason; whereas, 23\% \((3/13)\) were able to provide a rebuttal with a valid reason. It indicates that for this group of participants, overall, they have a relatively naïve or intermediary understanding of SA.

**Correlation analysis.** A two-tailed correlation analysis was conducted to further examine the internal relationships among the three components of generated scientific argumentation. The Argument domain was strongly, positively related to the Counterargument domain \((r = 0.62, p < 0.05)\). The Rebuttal domain was not found to be significantly related to either Argument or Counterargument domains. This means that participants who provided informed understandings of arguments generated informed counterarguments by providing two or more valid reasons.
Summary. Generally, most participants were able to provide an argument, a counterargument or a rebuttal with one or more valid reasons. Nevertheless, only a very small number of participants were able to demonstrate an informed understanding of scientific argumentation across all three components: Argument, Counterargument, and Rebuttal. In addition, a significantly positive correlation between Argument and Counterargument showed that participants who held relatively informed views of Arguments were able to generate informed Counterarguments.

Research Question 3: What are the characteristics of the relationships between a group of secondary science teachers’ understanding of NOS and their competence in understanding scientific argumentation about SSIs?

To answer this question, participants’ responses to antipolar items were converted into the equivalent positive form to make the numerical entries consistent with the intent of the survey constructs. Correlation analyses among subscales of the SEVs instrument and components of SA of the SSI item were used to explore potential relationships between a participant’s understanding of NOS and SA. To gain more insights, a qualitative analysis of semi-structured follow-up interviews among five selected participants and their written responses to the SEVs survey and SSI item were conducted.

Correlation analysis. Responses to the SEVs instrument on NOS, and the items related to understanding of SA, were analyzed pairwise using correlation analyses to determine if any statistically significant relationships existed. An assumption is made that the responses of respondents who have a sound epistemological understanding of NOS (as assessed by the SEVs instrument) should logically have a positive correlation with their responses to relevant items assessing their competence of generating SA about the SSI item. That is, a logically coherent
cognitive representation of the relationships between NOS and SA should result in positive correlations among the items. Based on this hypothesized one-way relationship, a one-tailed test of significance was used. The one-tailed correlation analysis (p < 0.05) showed that: a) the IC (invented and creative nature of science) domain in SEVs is significantly and strongly positively related to the Argument component of scientific argumentation (r = 0.55, p < 0.05); and that b) the CT (changing and tentative feature of scientific knowledge) domain in SEVs is significantly and strongly positively related to Counterargument component of SA (r = 0.49, p < 0.05) (As shown in Figure 4.3). This means that respondents who showed more informed understanding of the invented and creative feature of the nature of science constructed stronger arguments, and that teachers who better understood the changing and tentative feature of the nature (CT) of science constructed stronger counterarguments towards the SSI – climate change.

Additionally, correlation analyses (one-tailed) between domains of SEVs and total scores on SA (SA_T) showed that only the CT domain is significantly and strongly positively related to SA_T (r = 0.62, p < 0.05, n = 13). This means that participants who showed more informed understanding of the changing and tentative feature (CT) of NOS constructed stronger SA of climate change in general.
Qualitative Analysis. To gain a more complete view of how ISSTs’ understanding of NOS is related to competence in generating SA, the results of the follow-up, semi-structured interviews (Appendix E, G & K) with five purposefully selected participants were closely scrutinized, as well as their written responses to the SEVs survey and the SSI item. Participants’ total scores of the CT (changing and tentative) subscale, NOS_T, and SA_T were compared to select participants for the interview as explained in the Methods chapter. The CT domain was included because it is significantly strongly related to, and more central to, scientific argumentation as described above. Moreover, based upon the above statistical analysis between domains of SEVs and generated components of SA, the invented and creative feature (IC) of science was also taken into consideration in this qualitative analysis section. Generally, a relatively higher total score of understanding of NOS_T does not mean, necessarily, that a respondent was able to generate informed components of SA. Nevertheless, a relatively informed view of the IC (invented and creative) and CT (changing and tentative) domains showed higher competence in generating components of scientific argumentation.

As mentioned above, five female ISSTs were selected for a follow-up interview, four pursuing or holding a master’s, and one pursuing a doctorate degree in education. Representative patterns demonstrating a variety of levels of understanding of NOS and competence of generating SA among the interviewees are provided below.

Low NOS_T and Low SA_T. Participant T2 self-identified as a Caucasian and had taught Chemistry among 9th through 12th graders for over 10 years. She showed less informed understanding of NOS and scientific argumentation. Regarding the SEVs survey, she scored low on both the invented and creative (IC) and the changing and tentative feature of scientific knowledge (CT) features of NOS, compared to other domains. With respect to her generated
components of SA, she received a score of 2, 1, and 1 on generating Argument, Counterargument, and Rebuttal, respectively; this was lowest among all responses.

During the interview, when asked about why she disagreed with the statement – “Some accepted scientific knowledge comes from human’s dreams and hunches” (IC_2), she explained that she did not think that accepted scientific knowledge comes from human’s dreams; instead, it was the scientific faith in the work itself leading to new discovery, despite the evidence of how the periodic table was conceived. She also did not perceive creativity as a necessary requirement in the development of science; yet she did think that scientists could discover or invent new knowledge and they have expectations before they conduct exploration. Regarding the changing and tentativeness of science (CT), she commented that theories and concepts change with the improvement of technology and through different groups of scientists building upon existing ones. Nonetheless, she considered contemporary scientific knowledge as a ‘true’ explanation of what happened, and thus was not tentative and would not necessarily change. She further considered explanations or knowledge included in peer-reviewed and published articles as ‘true,’ though they may change in the future.

About her understanding of components of SA, she explained that “An argument is a disagreement between two parties”, a counterargument “Would be how you would respond to it [the argument] if you disagree” and a rebuttal “Would be like a solution, or your responses, your feelings towards your argument [the disagreement]”. When it comes to practically generating arguments, she wrote that “We [US] are one of the leading polluters and we should set the trend for the world. It’s not fair that we are not taking care of the environment.” When further asked about her evidence to support the written argument during the interview, she said, “The fact that global warming is real” and further cited sentences from the passage that “Increased levels of
carbon dioxide and greenhouse gases. The temperature of the earth is changing.” Overall, this is tending in a reasonable direction. However, regarding a counter-argument, she mentioned that Professor Ponso would show her actual examples of human behaviors were not affecting the climate change without explanations. She explained that,

I guess he would look for articles that combat climate change and would show how climate change isn't really something that we would be worried about. For example, I am a teacher, and I recently just got a mailing of a booklet from a big-whale company, with all information that was false, and skewed and one-sided, saying that I should not teach climate change to my students because it is not real. So he [Professor Ponso] probably invents them.

Regarding evidence that she would show Professor Ponso to support her own argument, she preferred to use TedTalk videos, scholarly articles, PowerPoint presentations that support the validity of climate change.

**Medium NOS_T and Medium SA_T.** Participant T6 was also a Caucasian; she had taught earth science among 6th and 8th graders for more than 11 years. She held a medium understanding of the NOS and SA, overall. Interestingly, she scored high on the IC (invented and creative) domain and medium on CT (changing and tentative) domain at the SEVs survey. In terms of generating SA, she received scores of 3 on Argument, 2 on Counterargument, and 2 on Rebuttal, which was considered as medium overall.

With respect to her understanding of the invented and creative feature (IC) of science, she emphasized the importance of creativity in the process of science development, and provided an example of Steve Jobs and Apple, which stated,

… he was trying to do personal computing in a very different way. People have computers, but it wasn't that he was the inventor of the computer. He was trying to make it in the way that was novel and different from how people had used them [computers] or how they … look before. Well now we have everything [branded as] Apple, so I guess that would be a specific role of creativity in science.
Regarding the relationship between imagination such as humans’ dreams and hunches and how science develops, she commented that,

I think it's very important. When you think that's like some of the greatest discoveries of the past, specially [when] it has to do with astronomy … I think that definitely people are simplifying it, but they were observing the world and making a guess of why this would always happen, and once they have noticed this [what happened], maybe they came up with a possible reason, a hunch, [or] an imagination. They imagine that this could be happening, and then, they want to set it out to prove that their hunch was right or wrong.

She believed that some, but not all, theories in science will change in the future as new information is gathered and shared faster nowadays through internet than ever, and that more data points would lead to new trends or new theories. She further considered current scientific knowledge as tentative as a result of constant effort on gathering and synthesizing information about the world. She further explained that,

I think similar to the reason why they [scientists] thought the Earth was flat was because they looked into the horizon and then saw nothing after it. That was their current observations [at that time]; they were trying to explain nature and they did. But once they were able to get a bigger picture. I mean I think about this a lot with treatments around cancer, the more they can understand the role of different parts of our body, different cells etc., the more they can target what needs to be cured. So I guess back to the question, if you get new scientific knowledge, you are getting new explanations for what's happening.

About her understanding of SA, she thought an argument as claimed-to-be-true statement, a counterargument as its opposite, and a rebuttal as reasons for supporting the initial argument and thus not changing it. Her generated written Argument stated,

I do think my country (the USA) should agree to be legally responsible for limiting greenhouse gas emissions. We need to have the long-term health of our planet as an important factor in our decision making. Instead we are making short-term benefits a priority instead of caring about future generations. It is disappointing, to say the least. In addition, the world looks at the USA as a leader so if we make a decision that helps our planet, other countries are more likely to follow suit.

She was able to provide a counterargument with one valid reason. The written responses included, “Professor Ponso could show me another time period where greenhouse gases
increased, but then decreased again.” During interview, she added that Professor Ponso may agree to limit greenhouse gases through capitalism or the open market, not legal means. With respect to Rebuttal, she mentioned that she was not sure about what to react to Professor Ponso, and explained,

He might try to poke a hole in mine [argument] and say like, “Well we don't have enough like reliable data points. We only have this one time that it [the global temperature] has gone up with humans, so how can you really justify that it's the one with humans”. I would argue that the data points around Industrial Revolution, where when we started emitting more greenhouse gases was when we started watching the temperature changed again. I guess I could say to him that we might be wrong, but this is a correlation not a causation. But if we don't do anything about it, then the damage would be irreparable. So we have to try to do something about it.

*High NOS*T and Medium SA*T*. Participant T9, self-identified as African American, had a well-informed understanding of NOS and a medium understanding of SA. She further showed an informed understanding of IC (*invented and creative*) and CT (*changing and tentative*) domains. She provided Argument and Counterargument with two valid reasons and thus received a score of 3 for each, yet she did not provide a valid reason for Rebuttal.

When asked about whether she thought scientists discover or invent scientific knowledge during the interview, she responded,

I think all of these things that scientists discover are already there. It’s just a matter of stumbling upon it and proving what you have experienced, or what you think is happening is happening. But except technological advances, let’s say, Tesla. And even in that situation, I think it’s just a matter of finding new uses for things that already exist. I don’t think, I mean, computers are amazing, but there is nothing about the computer that was like invented, so to speak. It was just like taking principles and ideas that were already there and trying to use them to create something new. So, I don’t necessarily think scientists discover things, so to speak, I think they help to explain things that we experience in our everyday lives. … these are just reimaginations of concepts that were already there. You know, MRI is just like a huge magnet; nobody invented magnets, we just figured a way to use magnets in a different way and manipulate the mechanisms so that we can actually like, use it as a tool to see inside of a human body.
Her above responses indicated she believed that ways of discovering scientific knowledge and how such knowledge could be applied in the real world were creative.

She further agreed that accepted scientific knowledge could come from human’s dreams and hunches and included Kekule’s vision of the unsaturated 6-carbon ring of benzene as an example. This is not a commonly known aspect of the history of organic compounds, and indicates she has more knowledge than a typical, non-scientist might have about this historical incident.

She further believed that science “Is consistently changing and you just need to be ready to change with it,” and “It [a scientific concept] could be new as in addition to something we already knew, or it [a scientific concept] could be something new that is a complete departure from what we thought and understood as the truth.”

She perceived an argument as “A position you have on some stated facts or any kind of statement,” a counterargument as “A position against that initial person who has the original point of view,” and rebuttal as a statement provided by “The original person who has the original point of view.” She also commented that, “Evidence should always play a strong part in any kind of like scientific debate.” Her generated argument to the questionnaire stated,

Yes, I think that the US should agree to be legally responsible for limiting greenhouse gas emissions and keeping it stable, as it is a major consumer of fossil fuels. I agree with the scientific evidence that shows that the consumption of fossil fuels is responsible for the increase in the Earth’s atmospheric temperature. I also believe that if every nation does not do its part to at least slow-down the production of greenhouse gases, such as CO₂, it will have a devastating effect on the entire planet. The people on the planet – Earth – are all connected: we all breathe the same air and drink the same water. Everything that we do has and/or will have an effect on others. Every nation needs to take responsibility for the health and welfare of their citizens, as well as the citizens of the planet Earth.

Her generated counterargument regarding Professor Ponso’s explanation for his position included,
If Professor Ponso had scientific data showing that burning fossil fuels does not produce CO$_2$ emissions; that CO$_2$ and other greenhouse gases do not warm the Earth's atmosphere and the Earth's oceans; that the warming of the oceans is not having a deleterious effect on ocean life, then maybe I would be convinced of his position.

Regarding rebuttal, she mentioned that she would cite scientific data from peer-reviewed journals that support her argument, and further explained during the interview that,

If … they don’t believe in climate change or that they don’t believe that carbon dioxide emissions are warming the atmosphere, warming the planet, I would find several articles online and I would either suggest they read them [articles], or I would read them myself and then point out the fact that would rebut their point of view.

**Low NOS$_T$ and High SA$_T$.** Participant T11 majored in physics and taught high school physics for less than two years. Interestingly, T11 demonstrated low understanding of NOS in general, but a well-informed understanding of SA. She showed medium understanding of IC (invented and creative) domain and informed understanding of the CT (changing and tentative) domain. Yet, she generated all three components of SA with two or more valid reasons and thus received a high score of 9 in total.

In order to better understand the abnormality here, her responses to the IC domain in the SEVs survey was examined. It was found that she chose strongly disagree with the statement that “Some accepted scientific knowledge came from human’s dreams and hunches,” (IC$_2$) and thus received a score of 1 on this item, which led to the “medium” understanding here. During the interview, she explained that she would agree with it if adding that these dreams and hunches would require validation by research later on to the statement. Therefore, here her understanding of IC domain could be considered as high, given her clarification.

Regarding the role of creativity, she commented, “I think creativity is a huge part of deciding what to collect and how to analyze it. Then ultimately you need to validate what you are
claiming.” She further believed that new information would lead to change existing concepts in science, which further leads to the change of scientific knowledge. She further clarified that,

I would say the more dramatic the change of the concept, the stronger the supporting the data and analysis must be. And necessarily, we need to continue changing the concepts over time. I teach physics and I often talk about Einstein when he first learned about quant-mechanics. … He couldn’t believe that the universe is based on probability; it turns out that is how quant-mechanics works. So you have to change your fundamental concepts of what is true in order to incorporate new scientific understanding into your way of looking at things. And that this is what science is. It is that the change when there is new information.

In addition, she perceived an argument as a claim that must be supported with evidence that can be validated, a counterargument as a counter-claim with its own set of supporting evidence, and a rebuttal as a bridge that sits between the back and forth process of argumentation. As mentioned above, T11 generated all three components of SA with two or more valid reasons. Her written argument stated that,

My country should agree to be legally responsible for limiting greenhouse gas emissions. First, it is clear that greenhouse gas emissions are destructive to the environment and contribute to global climate change. Although temperatures naturally fluctuate over thousands of years, the recent overall temperature increase has been more rapid than any before. This can be seen in the famous hockey-stick diagram [showing how temperature changes overtime]. It's possible that global temperatures would be rising today even without human activity; however, it's widely accepted at this point that human activity has a pernicious effect on our climate. Second, governments have a responsibility to preserve the world for future generations – and agreeing to the Kyoto Protocol is important in fulfilling that mandate. Individuals often act in their own best interests without regard to broader society or the future, as can be seen in myriad “Tragedy of the Commons” cases. One reason people establish governing bodies is in order to ensure that society's broader needs are met when individuals are unlikely to provide it themselves. For example, we enjoy the privileges of public transportation, public schools, and a police force. Protecting the environment for current and future generations is just another responsibility that falls in this category. Thus, because our country materially contributes to global climate change via greenhouse gas emissions, and because our government has a responsibility to preserve the environment, it follows that our country should create an accountability mechanism to ensure that it limits greenhouse gas emissions.

Her counterargument from Professor Ponso’s perspective explained that,
Professor Ponso argues that our country should not enter a binding agreement to limit greenhouse gas emissions. There are two components of my argument and Professor Ponso would need to disagree with either or both components: (1) that human activity (in particular from our country) materially impacts the environment, and (2) that it's the government's responsibility to preserve the environment above other competing priorities (such as economic gain). For (1), Professor Ponso would most likely argue that temperatures fluctuate naturally over the course of global history, and one cannot know for sure what or whom is causing the problem. And if it's not clear that there is a problem or that our country's citizens are causing it, then it would not be our country's responsibility to fix it. For (2), Professor Ponso would likely argue that it's not the government's role to protect the environment at the expense of economic stability or other priorities. Or, he may argue that it's a good idea for the government to try to limit emissions, but there's no reason to enter a binding agreement for which our compliance has no clear direct benefit to our country. He might also argue that it's not fair to make our country limit emissions when emerging economies are not asked to make the same sacrifice, and so our country should not be held responsible because it wouldn't be fair to us.

She further explained how she would respond to Professor Ponso that,

I would reply to Professor Ponso by defending both components of my argument. Regarding (1), I would point out that at this point it's widely accepted that emissions resulting from human activity are materially impacting the global environment, and it is likely to create myriad problems for ours and future generations. As I mentioned above, even if global temperatures would be rising anyway, the current rate of change is unprecedented (based on data from ice core samples). Furthermore, since my country is the USA, it's easy to measure my country's rate of emission, and it's one of the highest in the world. So my country is a big part of the problem. Since it's clear that there is a problem and our country is a big part of it, I'll move onto component (2) to explain why our government should agree to fix it. I agree that limiting emissions may have a negative effect on our economy in the short term, but the long-term benefits of environmental preservation are worth it. Large-scale economic preservation initiatives also result in innovation, which can even boost the economy – take, for example, the wind- and solar-power industries. Regarding the fairness component of the argument, it's just another logical “Tragedy of the Commons” fallacy. Instead of asking “Why don't emerging economies like China and India have to limit emissions?” we should be asking, “What can we do to preserve our world, regardless of whether others are doing it too?” Our government should do the work to take care of our planet.

Medium NOS_T and Low SA_T. Participant T12, with a geology background, taught for less than 10 years and had led workshops regarding SA. She scored medium on NOS and low on generating SA overall, a peculiar finding given her report of having led workshops on SA. A close examination of her responses to the SEVs survey showed that she had a low understanding
of the inventive and creative (IC) and changing and tentative (CT) features of science. She received score of 1, 2, and 2, on generating Argument, Counterargument and Rebuttal.

She did not believe that scientists discover or invent knowledge, instead, scientists try to find the best ways to explain the world. She clarified during the interview that,

I feel like in science, we are always trying to come up with the best explanation that we can, and we are able to get. But as we evolve, we develop more technology … we get more evidence … Our process of getting the evidence changes the explanations over time. So I wouldn't say that the knowledge that we had originally thought [or] discovered, was wrong. It's just the best thing we can come up with at that time. … I think it's a human-composed construct with the knowledge that we're defining and describing crosses the scientific community. Like plate tectonics. We used to think the continents drift around, move around; and now we know what we know – Knowledge, right? Now we know there is sea force driving it. But I don’t know if it’s that we discovered that or we just have the evidence to support a better explanation over time.

She also believed that there is something outside of human construct about how the world works, and commented that, we human being may get closer and closer to a more accurate explanation as we gather more evidence and technology advances.

She considered creativity as something novel and something that requires us to shift our current paradigm. Within science, she believed that creativity helps to come up with better explanations based on collected evidence; she further explained that,

I think that requires creativity to detain what we find in the evidence and make claims about it. It requires creativity in that process or developing explanatory models for causal mechanisms. … And then explanations, investigations about how we started something, technology that we developed to study something better, protocols, procedures, and things like that require creativity. And the ways that things are communicated can also require creativity.

T12 believed that imagination and creativity are related, and that people’s hunches could get better as you are more immersed in the field. She agreed that theories and concepts within science would change when evidence changes. She did not prefer to describe current scientific
knowledge as “Tentative”, as it does provide the best explanation in contemporary time, though she agreed that such explanations shall change as new evidence is discovered.

With respect to her understanding of SA, she explained that even the same evidence may point to two directions, which included argument and another one opposing it – the counterargument; the rebuttal provides a chance to critique the counterargument. As mentioned before, T12 did not provide valid reasons supporting her argument; she commented during the interview that, “… The socio-scientific issues is a much harder area for me to talk about, because I’m not as comfortable. I don’t know about the social part of socio-scientific issues.” When further asked to further explain her written responses to the questionnaire, she said that,

I think because of that power [US being a wealthy and powerful country], we should always try to think of the impact that our decision-making can have on other countries, and that influences other countries’ decision-making. If we show that we’re … willing to take a hit economically to do something better to preserve the planet, we can model that behavior for other countries to do the same. It is worth it. … I absolutely will say we should’ve agreed to be responsible for this … given all the evidence we have about global warming.

It is important to point out that not until she was further asked to provide scientific evidence, she mentioned evidence such as human-caused changes in global temperatures. In terms of the counterargument, she responded in the questionnaire that, “He [Professor Ponso] could try to argue that climate change is due to natural causes, not human-related causes.” She further added that during the interview that, “The other counterargument that I can think of is someone coming up and saying that is too late, nothing we do now is going to matter anyway, so we should protect our economy.” As to rebuttal, she explained that, “I would like to go through the data and say that based on patterns that we see … it [the pattern] doesn't show that this is what we would be experiencing now … even if there are fluctuations.”
Summary. To summarize, ISSTs who showed an informed understanding of NOS did not necessarily generate informed components of SA. A correlation analysis between domains of NOS and components of SA showed that the IC (invented and creative) and the CT (changing and tentative) features of science significantly relate to Argument and Counterargument, respectively. Examination of qualitative data including responses to the SEVs survey and SSI item among selected ISSTs further supported such a trend.

Research Question 4: Is there evidence that a group of secondary science teachers can apply some of the basic modern ideas of scientific argumentation after completing the online module?

Descriptive statistics on pre- and post-tests (questions 1 to 5). As mentioned in Chapter 3, pre-test (Appendix I) and a post-test (Appendix J) surveys were administered to evaluate the learning gains before and after participants completed the online learning module about SA from a theoretical stance. The same five questions used in the pre-test, which were in Likert-Scale format, varying from strongly disagree (1) to strongly agree (5), were also included in the first part of the post-test. The trends of participants’ responses before and after learning are reported as frequencies for the responses to the options in each item on the pre- and post-test measures (Table 4.3). The responses to the pre- and post-test items were diversely distributed among the options selected for the items; therefore, the results for each item will be analyzed individually rather than in groups as was done in Table 4.1.

In general, the respondents’ responses to the pre-test items indicated that this sample of ISSTs began with a fairly advanced understanding of some of the topics assessed in the pre-test (Table 4.3). However, there were notable (though not major) gains on the post-test for some items. On the pre-test, Items 1, 2, and 5 particularly show a high frequency of correct responses.
Nevertheless, for Item 3, eight of the 13 respondents chose neutral, indicating that they were not particularly confident about which answer was correct, and only four chose the disagree options that are the correct answers for this anti-polar item. For Item 4, also an anti-polar item, slightly more than half (eight) of the respondents properly chose the correct disagree options. Two chose neutral, and three chose the incorrect options in the agree range. Responses to Item 5 were correct in both the pre- and post-test surveys.

Table 4.3.

<table>
<thead>
<tr>
<th>Items</th>
<th>SD</th>
<th>D</th>
<th>N</th>
<th>A</th>
<th>SA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. During scientific argumentation, people use scientific language such as claim, evidence, warrants, counter arguments etc. to organize their points of view. Sometimes, two or more people will each take a position of approving or disapproving a scientific conclusion and try to persuade each other.</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>8</td>
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<tr>
<td>Pre</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>2. Science educators pay attention to scientific argumentation as it helps students to gain a deep understanding of scientific knowledge and how science is developed, including improving students’ understanding of the language of science.</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Pre</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Post</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>3. Scientific argumentation is an important current idea in teaching science, but it has not been emphasized in the Next Generation of Science Standards, because it is not one of the important practices of science*.</td>
<td>3</td>
<td>1</td>
<td>8</td>
<td>0</td>
<td>1</td>
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<tr>
<td>Pre</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post</td>
<td>7</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>4. The development of science largely progresses due to revolutionary ideas, often by one person, not the result of a community of scientists*.</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Pre</td>
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<tr>
<td>Post</td>
<td>4</td>
<td>7</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>5. Scientific argumentation can foster science literacy through enhancing public understanding of science; thus, enabling use of scientific language about socio-scientific issues.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Pre</td>
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<td>Post</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>9</td>
</tr>
</tbody>
</table>

Note. a)*These items are antipolar, which means that a disagree or strongly disagree indicates informed expected understanding of the provided information.
b) SD: Strongly disagree; D: Disagree; N: Neither agree or disagree; A: Agree; SA: Strongly agree.
In the post-test survey, there were only minor changes in responses to Item 1. However, for Item 2, all of the respondents accurately responded, with a minor gain of two accurate responses compared to the pre-test. For the anti-polar, Item 3, nine respondents chose the correct responses (disagree or strongly disagree) as opposed to four who responded correctly on the pre-test. Also, there was evidence of greater assurance in their responses to Item 3, moving from eight responses that were neutral to only one on the post-test; and nine respondents properly chose correct options in the “agree” range.

Given the relatively high scores on the pre-test survey for some items, the gains after experiencing the learning module are approximately what might be expected. The largest gain shown in Item 3 (change from four to nine correct), interestingly, also showed that there was some confusion, because three respondents chose the incorrect options on this item. Overall, there were only modest gains, for most items. However, when the data in Table 4.3 are expressed as percentage of total responses (Table 4.4), some trends are more apparent.

In Table 4.4 the antipolar items (items 3 and 4) were also converted into positive responses consistent with those that were from positive polar items. This percentage table provides a more detailed trend in terms of how ISSTs’ understandings changed after they completed the learning module about SA. This was what was expected as these evaluation items were summaries of the content included in the online learning module. For instance, these items evaluate a) how ISSTs understand the definition of SA (item 1), b) importance of SA in science education (item 2), c) SA and the Next Generation Science Standards (item 3), d) relationship between the community of scientists and science (item 1), and e) relationship between SA and science literacy (item 5).
Table 4.4.

Frequencies of pre- and post-tests in percentage after converting the antipolar items\textsuperscript{a}

<table>
<thead>
<tr>
<th>Items</th>
<th>SD</th>
<th>D</th>
<th>N</th>
<th>A</th>
<th>SA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 1 Pre</td>
<td>7.7%</td>
<td>30.8%</td>
<td>61.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post</td>
<td>15.4%</td>
<td>46.2%</td>
<td>38.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 2 Pre</td>
<td>7.7%</td>
<td>7.7%</td>
<td>38.5%</td>
<td>46.2%</td>
<td></td>
</tr>
<tr>
<td>Post</td>
<td>38.5%</td>
<td>61.5%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 3 Pre</td>
<td>7.7%</td>
<td>61.5%</td>
<td>7.7%</td>
<td>23.1%</td>
<td></td>
</tr>
<tr>
<td>Post</td>
<td>15.4%</td>
<td>7.7%</td>
<td>7.7%</td>
<td>15.4%</td>
<td>53.8%</td>
</tr>
<tr>
<td>Item 4 Pre</td>
<td>7.7%</td>
<td>15.4%</td>
<td>15.4%</td>
<td>38.5%</td>
<td>23.1%</td>
</tr>
<tr>
<td>Post</td>
<td>7.7%</td>
<td>7.7%</td>
<td>53.8%</td>
<td>30.8%</td>
<td></td>
</tr>
<tr>
<td>Item 5 Pre</td>
<td>53.8%</td>
<td>46.2%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post</td>
<td>30.8%</td>
<td>69.2%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\textit{Note.} a) \textsuperscript{a}n=13.  
b) SD: Strongly disagree; D: Disagree; N: Neither agree or disagree; A: Agree; SA: Strongly agree.

On item 3 (Row 3, Table 4.4), the percentage of participants who selected neutral dropped from 61.5\% to 7.7\%; and those who selected agree and strongly agree, actually doubled – they increased from 7.7\% to 15.4\% and from 23.1\% to 53.8\%, respectively, after learning. A similar trend was detected for item 4 (Row 4, Table 4.4). Before learning, respondents’ responses distributed widely from strongly disagree to strongly agree; a combined 38.5\% of the participants chose strongly disagree (7.7\%), disagree (15.4\%) and neutral (15.4\%). After learning, only a total of 15.4\% chose strongly disagree (7.7\%), and for neutral (7.7\%). Whereas, 84.6\% chose agree or strongly agree. It was a 23\% increase with a 15.3\% increase from those chose agree and 7.7\% increase from those chose strongly agree. However, unlike the other four items, item 1
Row 1, Tables 4.3 and 4.4) showed a decrease in teachers’ understanding of scientific argumentation, as participants’ responses shifted from strongly agree to agree and neutral. This item was among the more complex involving several aspects of argumentation, including logical reasoning, social constructivist aspects, and the role of persuasion. The number of participants who chose strongly agree decreased from 61.5% to 38.5%; whereas, the percentage of those who chose agree increased from 30.8% to 46.2% and those who chose neutral increased from 7.7% to 15.4%. The reason(s) for this change toward the negative pole are not immediately apparent, but possibly the complexity of the several aspects may have caused the respondents to be less confident in their answer, especially the last emphasis focusing on persuasion as part of SA.

Additionally, how SA was defined in the online learning module may have caused the confusion. SA was defined as “A dynamic interactive process (at an individual or social level) of using evidence to justify, validate and/or critique the coherency or strength of a scientific position that is being presented as an argument”. This definition focused relatively more on the perspective of “Approving” a scientific conclusion rather than “Disapproving” one. Nevertheless, the second part of the item 1 statement – Sometimes, two or more people will each take a position of approving or disapproving a scientific conclusion and try to persuade each other – emphasizes both on “Approving” and “Disapproving” a scientific conclusion. This might have caused the uncertainty among respondents.

Open-ended questions in post-survey (questions 6 to 10). In the post-test survey, there were five additional questions beyond those included in the pre-test survey, and these were intended to gain additional insight regarding how the ISSTs perceive the learning module, including how and what types of learning modules might be beneficial. Four of these questions (Question 6 to 9 in Appendix J) were included as Likert Scale items, and each was followed by
an open-ended question that asked participants to provide more details regarding their responses to the Likert item. The fifth-added question (Question 10 in Appendix J) was a binary choice (‘Yes’ or ‘No’) item to determine how confident the participants were that they could write learning objectives for teaching topics about SA, and it is addressed at a later point in this chapter under the side head of: Generated learning objectives (Question 10).

**Descriptive statistics (Questions 6 to 9).** Table 4.5 presents the frequencies for responses to Likert Items 6-9 regarding the merits of the learning module, as mentioned above. It shows the characteristics of ISSTs’ perceptions of this online learning module. Overall, teachers’ perceptions of this learning module are oriented towards the positive end of the option scale, especially Item 7. Ten out of 13 respondents agreed or strongly agreed with Item 7, meaning that they think they can visualize how SA can be used in lesson planning after completing the online learning module. About half of these participants (i.e., six or seven) agreed or strongly agreed with Items 6, 8 and 9.

Table 4.5.

**Frequencies of agreements on participants’ perceptions of the online learning module**

<table>
<thead>
<tr>
<th>Items</th>
<th>SD</th>
<th>D</th>
<th>N</th>
<th>A</th>
<th>SA</th>
</tr>
</thead>
<tbody>
<tr>
<td>6. This online learning module helps me to gain a deeper understanding of scientific argumentation.</td>
<td>1</td>
<td>0</td>
<td>5</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>7. After going through this online module, I can see how scientific argumentation can be used in lesson planning.</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>8. This online module can help me with my lesson planning regarding scientific argumentation.</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>9. This online module would allow me to teach scientific argumentation based on what I learned.</td>
<td>0</td>
<td>1</td>
<td>5</td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>

*Note. a) n=13. b) SD: Strongly disagree; D: Disagree; N: Neither agree or disagree; A: Agree; SA: Strongly agree.*
Qualitative analysis of written responses (Questions 6 to 9). Item 6. Item 6 (Row 1, Table 4.5) addressed whether this online learning module helped ISSTs gain a deeper understanding of scientific argumentation. Seven teachers agreed or strongly agreed with the statement; whereas, one strongly disagreed with it and five remained neutral. Further written explanations provided more details in terms of how this online learning module fostered their understanding of SA. It appeared that this module a) “Broke up exactly what SA [scientific argumentation] is” (T2), b) “Broke up the reasons for using scientific argumentation into easy to understand segments” (T10), and c) provided a “Rigorous definition of Scientific Argumentation” (T11). Another teacher who agreed with the statement mentioned that, “The graphic helped me to see the connections between scientific argumentation and science education.” (T6)

Two teachers who chose neutral stated that “It was useful to see all of these ideas in one place. A couple of the visuals helped put things in perspective.” (T3); and that “It was nice to see the example of 2 scientists’ thoughts.” (T12) Overall, according to the self-reported explanations from ISSTs choosing strongly disagree or neutral, they already had a good understanding of SA before participating in the study. Examples of evidence for their prior knowledge included: “It [the learning module] meshed well with what I had already learned.” (T4) and “I already know a great deal about this topic.” (T13)

Item 7. Regarding Item 7 (Row 2, Table 4.5), “After going through this online module, I can see how scientific argumentation can be used in lesson planning,” ten teachers agreed or strongly agreed; compared to two and one teacher(s) who chose disagree and neutral, respectively.
Among those who responded favorably, their visions of how SA could be implemented in lesson planning varied from focusing on “Guiding questions or prompts for students when we are doing activities,” (T2) doing “Experiments to help students understand how to make a claim and support it with evidence,” (T5) “Collecting and analyzing evidence, and then using like ‘real’ scientists, students engage in the process of science and make meaning for themselves,” (T6); and “Teaching of Scientific Method.” (T9) One teacher who agreed with the statement provided a more comprehensive comment, saying that,

SA [scientific argumentation] can be implemented during many phases of lessons, including evaluating claims during discussions and drawing and defending conclusions during labs. The module showed how scientific argumentation would both help students improve conceptual understanding and scientific vocabulary as well as their understanding of the nature of science. (T4)

Another teacher who had prior experience applying SA in science classrooms and strongly agreed with the statement explained that,

Going through this module has given me an opportunity to reflect on my practice and consider if there is anything I could be doing better (implementing more effectively). The challenge for me in having scientific argumentation in the classroom is less what I am shooting for and the fact that I need to have it, and more in the technique of implementation. How to get students to go a little deeper, when they are most comfortable on a very surface level. How to have students all participate, instead of having a few students who are most comfortable in this kind of discussion carrying the whole show. How to create a classroom environment where students feel able, willing, and competent to have this kind of discussion. Going into sufficient depth, rather than me, as the teacher, being content with a superficial level of engagement. (T3)

Three ISSTs selected neutral or disagree. One was the teacher who chose neutral. She self-reported that she already knew a lot about SA (T12). The remaining two who chose disagree explained that “I rarely use scientific argumentation in my daily lesson planning,” (T1) and that “Not a whole lot on how to encourage students to use argumentation. Suggested scaffolding would be helpful.” (T10)
**Item 8.** When asked about the item “This online module can help me with my lesson planning regarding scientific argumentation” (Item 8, Row 3, Table 4.5), six ISSTs provided positive responses, while three chose disagree and four chose neutral. Among those responding favorably some exemplary responses included that they could “Require students to pick a side to a scientific argument,” (T1) “Use the diagrams to show students how theories, data, claims, counterclaims, etc. interrelate in a scientific argumentation dialogue,” (T11) and “Foresee students’ misconceptions.” (T13) Another three ISSTs provided responses similarly to item 7, saying that “I can focus on guiding questions or prompts for students when we are doing activities,” (T2) “I will embed this in experimentation,” (T5) and that “I can incorporate scientific argumentation as a part of teaching the Scientific Method.” (T9)

Interestingly, one teacher who remained neutral, said that: “It will inform me in a general way that I should use it. I may also use the graphic and show it to my sixth graders to explain the importance of what we are about to do.” (T6) Another one explained that, “I teach ELLs, so I would need additional support for facilitating argumentation.” (T7) Among the other five who disagreed or stayed neutral, three (T8, T10 & T12) mentioned that this module did not provide practical instructions in designing lesson plans using scientific argumentation. Such responses were expected as the module did not aim to provide practical skills, which was pointed out by T8. Two others (T3 and T4) disagreed due to their good prior understanding of SA.

**Item 9.** For Item 9 (Row 4, Table 4.5), “This online module would allow me to teach scientific argumentation based on what I learned.” In some respects, this item is a check on consistency in responding, because it has close similarity to Item 8. Indeed, the responses were closely similar between these two items. Generally, seven fell in the agree range here, and six in the agree range for item 8; seven out of 13 ISSTs in total recognized this in their written
responses. Among teachers who responded positively, two provided the same responses as to Item 8; one stated: “I'm not sure how this question is different than the previous two.” (T5) Other respondents gave other insights into their perspectives. For example: “I definitely feel more confident and excited to incorporate explicit teaching of SA into my curriculum.” (T8) “I would feel comfortable teaching students what scientific argumentation is, why it's important to them, and how to do it.” (T11)

Two out of six ISSTs who disagreed or remained neutral, two teachers found this learning module was not advancing their knowledge of scientific argumentation due to their considerable prior knowledge. Three others were more balanced in their views and thought this module fostered their understanding of SA, but it was not advancing their practical skills in implementing it. Therefore, they suggested including hands-on workshops to augment the online module. Examples of such comments included: “A workshop, with a small group of committed participants, where methods could be described, discussed and tried out would be needed.” (T3); and somewhat more nuanced, “I think I could teach what argumentation is, but not how to properly use it.” (T10)

**Generated learning objectives (question 10).** As mentioned above, the last item (Question 10 in Appendix J) was a binary question with “Yes” or “No” options, asking “Could you write learning objectives for a lesson that you may implement with scientific argumentation based on what you have learned from this online module?” Eleven teachers chose “Yes,” and only two chose “No.” Those who chose “Yes” were invited to submit examples of an appropriate learning objective. Examples are presented in Table 4.6. Given that this task asked for the additional commitment of the respondents’ time and thought, it was encouraging that 11 chose to make considerate responses.
Table 4.6 showed that most of these learning objectives emphasized that students should be able to use data or evidence to support or evaluate their claims. Yet, it did show a spectrum of focus when it comes to implementing SA into lesson planning processes despite teachers’ prior backgrounds; this includes having students form a claim (e.g., T10 & T11), analyze a claim (e.g., T4), generalize a conclusion (e.g., T1 & T5) and create a model (e.g., T8). Three participants (e.g., T2, T6 & T11) mentioned a social process of learning by having students listen to and engage in discussion and debates with their peers.

Table 4.6.

Samples of generated learning objectives listed for each respondent (T)

<table>
<thead>
<tr>
<th>Generated learning objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
</tr>
<tr>
<td>T2</td>
</tr>
<tr>
<td>T4</td>
</tr>
<tr>
<td>T5</td>
</tr>
<tr>
<td>T6</td>
</tr>
<tr>
<td>T7</td>
</tr>
<tr>
<td>T8</td>
</tr>
<tr>
<td>T9</td>
</tr>
<tr>
<td>T10</td>
</tr>
<tr>
<td>T11</td>
</tr>
<tr>
<td>T13</td>
</tr>
</tbody>
</table>

*SWBAT stands for “Students Will Be Able To… (action verb describing what will students can achieve at the end of the lesson)”. It is a format for generating learning objectives.

**Holistic case-analysis of learning gains.** Though ISSTs’ understanding of SA was relatively well-formed before they started the learning module, two participants, T5 and T8, who
had low pre-survey scores showed a large change towards the positive in the post-test survey.

After converting the antipolar items (item 3 & 4) into the regular format, the detailed changes of their perceptions of these items are presented (Table 4.7). Their responses were analyzed as case studies of two respondents who showed the most gain from the learning module.

Table 4.7.

*Learning gains represented as change in the Likert-item option values after converting antipolar items for the pre- and post-test instruments where the option scale was from 1 to 5.*

<table>
<thead>
<tr>
<th></th>
<th>Item 1</th>
<th>Item 2</th>
<th>Item 3*</th>
<th>Item 4*</th>
<th>Item 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>T5 Pre</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>T5 Post</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>T8 Pre</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>T8 Post</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

*Note.* * indicates that these were antipolar items.

T5 showed strong gains on Items 2, 3, and 4, while progressing from a score of 4 to a score of 5 for Item 1 (Table 4.7, row 1 and 2). She self-identified as a Caucasian female with a biology background and who held or was pursuing a master’s degree. She had taught for more than 10 years and had not participated in workshops related to SA. She showed a medium understanding of the ‘changing and tentative feature of science’ (CT) domain and NOS in general; she scored medium on the item ‘proving scientific argumentation’ of the SSI instrument. She demonstrated the most gains after using the online module, especially on Items 2 and 4. Before learning, she disagreed with the statement of Item 2; after learning, she strongly agreed with the statement. After learning, she thought that SA could help students to gain a deep understanding of scientific knowledge and the process of science development. For Item 4 (antipolar), she changed her response from agree to disagree. This showed that, after completing the online learning module, she did think the accumulated effort from the community of scientists fosters the development of science.
In addition, she provided favorable responses for Items 6 to 9. She thought that the online learning module helped her gain a deeper understanding of SA. She commented that,

Previously I was thinking of scientific argumentation as two scientists with opposing views arguing a position. The module showed me that it is a lot more than that. It's [about] scientists using data to defend a position and explain things. This is something I do in my classroom and would like to do more.

In terms of applying SA as part of her lesson designing process, she stated that she intended to use it during experiments so that students could understand how to make claims and support them with evidences. This response was consistent across all four items.

Another teacher (Caucasian male) T8, who showed strong gains on Items 2 and 3, while already scoring high on the other items (Table 4.7, rows 3 and 4), had a similar background to T5. He had taught for less than five years and had attended prior workshops about SA. He scored high on the CT domain, SEVs survey (NOS_T) in general and was informed in providing SA of the SSI item. He showed similar learning gains to T5 (especially Items 2 and 3). His perception towards Item 2 changed from strongly disagree to agree. For Item 3 (antipolar), he chose neutral before learning and strongly disagree after. After learning, he strongly agreed that SA is an important practice of science.

Regarding items with open-ended questions, he strongly agreed with Item 6, indicating that the learning module helped him to gain a deep understanding of SA. His comments included:

The diagram with “ARGUE, CRITIQUE, ANALYZE” in the middle really helped me understand just how central SA [scientific argumentation] is to the process of science. The module helped me see SA [scientific argumentation] as a bridge between all the other steps I was familiar with in the scientific process (asking questions, gathering data, forming/testing theories, etc.). In addition, it helped me see the importance of teaching SA [scientific argumentation] to students in an explicit way. By helping them learn how to use words such as claim, evidence, and warrant, they can come to see science as an examined set of evidence-based conclusions about the real world, not intuition-based opinions (even if those opinions are informed).
He strongly agreed that this learning module helped him visualize how scientific argumentation can be used in the lesson planning process (Item 7) and explained that:

I have struggled to help students connect evidence with real conclusions and avoid mere “Gut feelings” that depend on naive intuition. I think that the language in SA [scientific argumentation] may help significantly. I also feel like I can justify to my students the importance of discussion and argumentation in class by showing them that it is an inherent and vital part of the scientific process. I also have a better sense of where SA [scientific argumentation] should be incorporated into the process. At the beginning of the year, I would simply teach my students the language around SA [scientific argumentation] (claim, warrant, etc.) and help them grow comfortable using those words. Then, I would give them opportunities to employ that language in an authentic way through experimentation and modeling of theories.

He surmised that: Even though this learning module did not provide specific information regarding practical lesson planning of implementing scientific argumentation, it did improve his confidence in teaching SA explicitly in his classroom.

**Analysis of follow-up interviews.** All five participants that were selected for a follow-up interview (Appendix K) were asked about their perceptions of the learning module and what they would expect to gain when participating in a workshop about SA. Results from the interviews were consistent with teachers’ written responses in the post-test survey but provided more details.

Among five ISSTs interviewed were five females (four Caucasian and one African American); one of each majored in chemistry (T2), biology (T9), and physics (T11), and two majored in geology (T6 &T12). Four teachers held, or were pursuing, a master’s degree and one held or was pursuing a doctorate. Three out of the five ISSTs show some learning gains on pre-post surveys; but the remaining two did not show learning gains after completing the learning module. A brief view of each participant’s learning gains is provided below.
T6, who had taught middle school earth science for more than 11 years, evidenced good learning gains. Her responses for Items 3 (antipolar) and 5 changed from neutral and agree to strongly disagree and strongly agree, respectively. She agreed that the learning module improved her understanding of SA (Item 6) and she was able to see how SA could be used in the lesson planning process (Item 7). Though she remained neutral on Items 7 and 8, she did provide positive comments that this module helped her in a general way of implementing SA in lesson planning. Some detailed comments she provided during the interview stated that, the learning module:

Really helps to tie in like why we should be doing science that's not just about like memorizing content, learning new content, but instead like using it in a living way for kids that are using it to argue and to backup, you know, theories and ideas, and the counterarguments of other students…. I like the concept saying where this fits in the actual work that the teachers do every day and that we have to fit into the standards that we are reading.

Regarding expectations for related workshops, she commented that,

I think I would expect that we would talk about what makes a strong argument, how to support your argument with evidence, where to find that evidence, and then how to prepare to be ready for people arguing against your claims, like how to be prepared with the rebuttals. I also think a workshop should have a time where teachers get to step out of the teacher role and sort of be kids, and like practice what it would be like to actually be doing that as a student.

T11, who had taught high school physics for less than two years, showed similar positive learning gains compared to T6. She had not participated in a related workshop regarding SA before; yet she did implement some aspects of SA into her classroom teaching. Interestingly, she scored low generally on the SEVs survey, but high on the changing and tentative feature of science (CT) and SA. She changed her responses for Items 3 (antipolar) and 4 (antipolar) from neutral and disagree, respectively to strongly disagree for both, thus achieving strong positive gains. She further provided favorable responses toward items 6 to 9. According to her
explanations for these items, she enjoyed the rigorous definition of SA provided in this learning module and felt more confident and comfortable in teaching the definition and showing students the components of SA. She further explained in the interview that, “I think it’s very helpful to just give a definition of scientific argumentation and to help people ensure they are talking about it in the same way.” She further comments her understanding of SA and science literacy,

People often come to understand things through argument and debate, it enables them to form strong point of view of what they believe. And I understand the term science literacy like, the general public like being literate in science, or being able to read and speak in scientific terms and they will be able to understand it better through arguing about it.

T9, self-identified as African American with a biology background, had taught middle school science for less than five years. She had never participated in SA-related workshops and showed a medium understanding of NOS and SA in general. Her responses toward Item 4 (antipolar) changed from agree to strongly disagree. She agreed that the learning module fostered her understanding of SA; she strongly agreed that it helped her to see how SA could be used in the lesson planning process and to implement SA when teaching scientific method in the classroom. After learning, when asked about how she thought about the role of scientific argumentation in the process of science development, she explained that,

I think it’s a lot of back and forth. For instance, I took a class this semester in cognitive neuroscience, and we discussed a lot of what the instruct refer to as controversies in cognitive neuroscience where, one group of scientists found an area of the brain that they thought was specifically for doing one particular thing; and a bunch of other researchers, they developed a whole bunch of studies to trying to approve this person wrong. And I think that’s what scientific argumentation is. It’s not just like me standing up and going, “I am right, you are wrong” and the person who’s knowing “I am right, you are wrong”. It’s, you have to actually go back to allow and prove that whatever such a saying is actually true. Or you go and you find papers that support your point of view. It’s not anti-back and forth; it means to have something substantial to back up your point of view.
In terms of expectations about related workshops, she proposed using a debate club format where teachers taking different sides could learn to find valid information and improve their techniques on how to argue.

T2, with a background in chemistry, and taught high school physics for more than 11 years, had not participated in workshops related to SA prior to this study. She scored low on changing and tentative feature (CT) of science and NOS and SA in general. Pre- and post-survey items (Items 1 to 5) did not show learning gains. Yet, she provided favorable responses toward Items 6 to 9, as she enjoyed the fact that the learning module “Broke down exactly what SA [scientific argumentation] is” with an example of two scientists’ discussion process and a flow chart of the importance of SA; therefore, it helped her with lesson planning and teaching processes in terms of using guiding questions or prompts of SA for students during activities.

The sample learning objective she generated was: “Students will be able to listen to students’ claims and analyze the validity of them. Students will look at two sides of the argument and decide on their positions.” When asked about expectations of attending a workshop related to SA during the interview, she asked for practical techniques in modeling a debate in a scientific classroom, practical examples or debate topics within different science disciplines, and access to potential resources regarding how to facilitate student learning activities.

Similarly, T12, who taught for less than 10 years, did not show learning gains for pre-post surveys (Items 1 to 5). She showed lower level understanding on the changing and tentative feature of science (CT), and received medium scores on SEVs survey generally and the SA of the SSI item. She self-reported with a well-informed understanding of SA and experience in facilitating related workshops. She did not think this learning module had improved her understanding of SA (Item 6) and stayed neutral for Items 7 to 9. During the interview, she
provided expectations of the workshop from two different stances: a) helping the general public to learn about SA and b) helping teachers guide students to learn to use SA. For the former case, she suggested using immersive experiences, where learners would actually feel the value and importance of SA and learn about the history of science, examples showing changes of theories through argumentation over time, and current ideas about the practice of SA. In the latter scenario, she said that,

    If I were trying to help teachers, then I would be not just the immersive part, but I would actually have them rehearse facilitating argumentation in the classroom with participants, having them watching videos of a classroom, or when the teacher is doing this successfully, sort of unpack what they've seen, try to create, do some generative work, create some materials that might engage them in practice so that they can then test them out with kids and come back and reflect on how it went. And so that they came first hand [and] see how that [scientific argumentation] plays out in a classroom, those are the things that I would do.

**Summary.** Overall, this learning module was able to improve participants’ understanding of SA despite their relatively informed understanding of SA from a theoretical perspective, as highlighted by the pre-test survey. The generated learning objectives showed that most of the ISSTs emphasized that students should be able to use valid evidence to support their claims or positions taken. Nevertheless, the focus of such processes varied from forming a valid claim, analyzing an existing claim, or generating a conclusion to creating a model. In terms of expectation of related workshops about SA, they would prefer workshops to provide them with practical techniques of facilitating SA, resources for various topics, and places to find valid information.
CHAPTER 5
DISCUSSION & CONCLUSIONS

The purposes of this study were to understand: a) characteristics of in-service secondary science teachers’ (ISSTs’) existing understanding of the nature of science (NOS) including sociocultural accounts, b) their competency in generating scientific argumentation (SA) about socio-scientific issues (SSIs), c) features of the relationship between their understanding of the nature of science (NOS) and scientific argumentation (SA), and d) explorative evidence showing that they can apply basic modern ideas about SA after completing the online learning module.

The findings regarding each intent are discussed in this section, followed by a holistic summary of all findings across all research questions and discussions.

In general, it is important to recognize as stated at pertinent places in the Results section (Chapter 4), that these ISSTs, overall, appear to have had an appreciable prior understanding of some of the aspects of NOS and SA that were addressed in this thesis (especially as exhibited in their responses to the pre- and post-test survey items related to aspects of the learning module). Therefore, the results of this thesis need to be interpreted in the context that this sample was a fairly informed group of teachers about NOS and SA. Nonetheless, as a first study of this kind, it was advantageous to begin with a more informed group, because it provided somewhat of a baseline investigation that can be used to build further studies with less-informed participants, not only in-service but also potentially preservice teachers. With this context in mind, a discussion of each Research Question is presented below.

**Research Question 1: What characterizes a group of secondary science teachers’ existing understanding of NOS including sociocultural accounts?**
Previous findings showed that science teachers do not possess adequate conceptions of NOS, particularly using modern, theoretically-based, instruments that have been used to measure it (e.g., Lederman, 2006). However, for this group of ISSTs, there was evidence that they possessed considerable basic understandings of NOS from a sociocultural perspective at the beginning of the study. Among all 19 Likert items, ISSTs’ responses were heavily distributed towards an informed view of NOS, but there were exceptions where they were less knowledgeable. For instance, T2 received a score of 70 on the SEVs survey (total score varies from 68 to 90 after converting antipolar items) indicating less informed understanding of NOS, a low score (score = 4) in generating SA (total score varies from 4 to 9) highlighting being less competent in understanding SA, and a medium score (score = 21) in pre-test (total score varies from 15 to 24 after converting antipolar items) before starting the online learning module.

Similarly, T10 received low scores across all three indicators – scores on SEVs, generating SA and pre-test were 78, 5 and 19 respectively. The correlation network diagram (Figure 4.1, Chapter 4) further highlighted the relative maturity of this group, especially evidence of coherence within this group of science teachers’ percepts regarding their understanding the NOS, both from epistemological and methodological perspectives.

This correlation network diagram included two clusters of nodes that on content analysis appeared to address particular themes: one of them, mainly including domains of CT (changing and tentative) and CU (cultural impacts) and representing the epistemology of science, was less densely linked (mean ratio of internal linkages to nodes = 0.8) with lower correlation values (mean r = 0.63); the one to the right mainly including TL (theory-laden) and SN (social negotiation), highlighting the methodology of science, was more densely linked (mean ratio of internal linkages to nodes = 1.3) with higher correlation values (mean r = 0.7). The themes
shown in the network diagram – epistemology and methodology of science – describe the nature of scientific knowledge and the process of its development, respectively; together, they represent how NOS is typically defined (Abd-El-Khalick, 2013; Lederman, 1992, 2004; Lederman & Zeidler, 1987). Additionally, there is a link between these two clusters of nodes. The node “New scientific knowledge requires group recognition” item (SN_1) bridges the two themes identified above; i.e., epistemological and methodological. This suggests that the SN_1 item might be perceived by this group of respondents as a more central organizing aspect of their percepts of NOS. The statement – *New scientific knowledge requires group recognition* – highlights the up-to-date socio-cultural constructivism nature of human learning, and thus how knowledge within various disciplines develops, including science. As such, it is a major pedagogical linking idea, and likely would be seen by teachers as a unifying or linking construct.

In Tsai’s and Liu’s (2005) paper on the SEVs instrument used in this study, the TL (*Theory-laden nature of scientific knowledge*) domain was more related to SN (*socio-negotiation*) perspective than other perspectives of NOS. Therefore, they predicted that the TL domain would be more central to NOS. That was supported by Kuhn (1962, 1970) who opined “Anyone who has attempted to describe or analyze the evolution of a particular scientific tradition will necessarily have sought accepted principles and rules of this sort” (p. 43).

Nevertheless, this function has not been fully realized in current science education, where the focus is shifted from what we need to know toward why and how we know, due in part to theories of cognitive development (Duschl, 2008). The practice of science is situated in settings including aspects of cognitive, epistemic and social practice; and thus, the characteristics of NOS “Shifted from “general heuristic principles toward cognitive and social elements” (Duschl & Grandy, 2012, p. 2109). However, even in this context, we need to recognize that the process of
the community of scientists responding to new data, and novel methods of analyzing and interpreting such information, is essential to the development of science and underlies the tentativeness of scientific knowledge. That is, science is inherently a social and professional community enterprise and the community norms and expectations are inextricably linked to the practices and products of scientific inquiry. This is in contrast to an empiricist view that emphasizes science always provides the ‘truth’ about nature.

As a summary, analysis of responses to all 19 Likert items in the SEVs survey showed that ISSTs held an informed understanding of the socially constructed feature of NOS. All 13 ISSTs agreed or strongly agreed with six regularly formatted items and disagreed or strongly disagreed with one anti-polar item. This is especially true when it comes to the social-negotiation domain (SN), where 10 (77%) ISSTs showed that they understood science proceeds by consensus among a community of researchers. Additionally, the inter-correlation network diagram not only highlighted the coherence of this group of ISSTs’ perception of science, but also addressed two themes of science from epistemological and methodological stances. Also, the socially structured nature of science was highlighted in the correlation network diagram. The fact that the SEVs item (SN_1) connects these two themes is consistent with current sociocultural constructivism view of learning, which further influences the epistemological and methodological development of science. Furthermore, there were three negative relationships in the network diagram – the statement that “different culture interpret phenomena in the same way” (CU_1) negatively related to three nodes, namely, “scientists agree on some research methods” (SN_2), “current knowledge may be changed or discarded” (CT_3) and “different cultures gain knowledge differently” (CU_3). As mentioned above (Chapter 4), these negative relationships highlighted the coherency among ISSTs’ understanding of the epistemology of
science. This was because these statements were logically inconsistently paired claims; negative correlations were expected to show the consistency in understanding among this group of ISSTs in this study.

**Research Question 2: How competent are a group of secondary science teachers in understanding scientific argumentation about SSIs?**

Although the results of this study related to Research Question 1 showed that ISSTs had an appreciable understanding of some of the dimensions measured by the SEVs instrument, teachers’ responses to the SSI item showed that few respondents provided evidence that they possessed a consistent set of informed perspective on components of SA or SSI. Nonetheless, most of them were able to provide an argument and a counterargument with one or more valid reasons. Existing studies have documented the lack of competency to generate highly developed argumentation among adults and young people, more generally (Kuhn, 1991; Mason & Scirica, 2006; Means & Voss, 1996). Teachers’ views about the role of SA influence how the practice of argumentation is implemented in classrooms, yet most science teachers lack the pedagogical knowledge and resources to design instructional practices to engage students in argumentative processes (Sampson & Blanchard, 2012).

In addition, results from the correlation analysis (two-tailed) of possible interactions among the three generated components of SA showed that respondents who demonstrated informed views of arguments also generated informed views of counterarguments, despite the poor quality of rebuttals. This is consistent with existing studies. For instance, Sampson and Blanchard (2012) conducted a qualitative study using cognitive appraisal interview for investigating 30 secondary science teachers’ understanding of argumentation and their abilities to generate it and found that most teachers generated argumentation without providing real
support (that is, without evidence of quality); instead using data, they evaluated the validity of explanations mainly based on their existing content knowledge.

One important point to emphasize here is that in judging the accuracy of ISSTs’ arguments, economically sound reasons were counted as evidence of scientifically sound reasons, especially for aspects of science that intersect with community economic challenges (e.g., global warming, etc.). Economics is generally accepted as a scientific endeavor, albeit largely a social scientific discipline. However, the challenge for teachers in assessing the adequacy of scientific arguments does hinge on what we accept as scientific evidence. According to McNeil and Berland (2017), what should be recognized as scientific evidence is unclear among all structures of SA, and thus they suggest narrowing what could be counted as evidence in science classrooms. According to them, a vexing problem within classroom instructional practice includes viewing science as a set of final form ideas, seeing data as the answer to explain the observations, and students passively gaining information. Therefore, they proposed a cohesive set of three approaches for using scientific evidence in instructional practice: phenomena-based (information is phenomena-based with empirical data), transformable (students should manipulate information to find and evaluate patterns to transform information) and dialogical (students should engage in social interactions to make sense of information); this would potentially help educators design effective learning opportunities. While this is defensible from an epistemological perspective on basic science, in the reality of modern science teaching, socially-relevant aspects also must be taken into consideration. This, obviously, places considerable pressure on the wisdom of the science teachers to make clear what aspects of science practices are grounded in basic science versus those that intersect with social and human collective needs. Even with deep understanding of how the development of science could be
influenced by social, political and moral aspects, ISSTs will still face challenges during instructional practices in terms of what approaches to take and resources to use in order to help their students better understand the problems of social and political pressures that often aim to intervene in, or suppress, the canonical practices and ethics of science; especially if the findings of science do not support politically identified goals, etc. as seems to be happening now with socio-scientific issues including global warming, genetically modified food and so forth.

**Research Question 3: What are the characteristics of the relationships between a group of secondary science teachers’ understanding of NOS and their competence in understanding scientific argumentation about SSIs?**

In this study, evidence suggested that informed understanding of NOS does not guarantee an informed view of scientific argumentation (SA). However, a significant correlation (one-tailed) between NOS and SA was found between some domains of NOS (SEVs survey) and components of SA. For example, the IC (*Invented and creative nature of science*) domain in SEVs is significantly and strongly positively related to the Argument component of SA; the CT (*Changing and tentative feature of scientific knowledge*) domain in SEVs is significantly and strongly positively related to the Counterargument component. Qualitative analysis also showed that ISSTs with a more informed understanding of the inventive and creative (IC) and changing and tentative (CT) features of science generated better SA, in general. The CT domain is further significantly and positively related to the total score ISSTs received in generating components of scientific argumentation.

These findings are coherent with existing theories. Bilican (2018) conducted a case study among five pre-service science teachers from an elementary science teaching program, where the nature of science was taught explicitly in a teaching methods course. It was found that an
improved understanding of the nature of science did not always result in improvement in justifications of arguments towards their decision-making about socio-scientific issues. The study also showed that all five pre-service science teachers possessed adequate but not informed understanding of the tentative feature of science. Additionally, evidence in Khishfe’s (2012) study among 219 11th grade students’ understanding of NOS and argumentation skills of SSI items – genetically modified food and water fluoridation – showed similar results. She found significant correlations between the tentative feature of science and the Counterargument within both SSI items. From a qualitative aspect, her examination to some extent showed a trend that respondents who held an informed understanding of NOS from subjective, tentative, and empirical perspectives; also demonstrated relatively developed skills in generating argumentation.

Moreover, in this study evidence indicated that ISSTs who held a well-informed understanding of the issues related to Changing and tentative nature of science (CT) generated well-informed counterarguments, and overall generated informed responses to components of SA. This feature of science is important to the new stage of normal science and its expansion, as scientific knowledge is subject to change; especially when new evidence surfaces due to new ideas and technology advancement (Hun-Young & Lederman, 2018). This current study employs a social-constructivist view of NOS, emphasizing the inferential, creative, and socially and culturally embedded features of science; and assumes that scientific knowledge is developed socially among the community of scientists through agreed theories, shared evidence and social negotiations (Hun-Young & Lederman, 2018; Tsai & Liu, 2005). Critical thinking skills are fundamental to such a view. Generating arguments, evaluating the credibility of sources and judgments, observation, deduction, causal relationship explanation, and general scientific
explanation are core concepts of critical thinking (Ennis, 1996). Engaging in interpretations of the tentativeness of science during scientific argumentation promotes critical thinking, and thus a deep understanding of NOS and better decision making on SSI (Yacoubian & Khishfe, 2018).

Additionally, the NSTA (1982) claimed that an adequate NOS understanding is related to the empirical and tentative feature of scientific knowledge. Their view of NOS highlighted an empiricist-aligned perspective, seeing the theories and inquiry as the center of science development. Studies in the early 90s showed that many teachers do not believe scientific knowledge to be tentative (Abd-El-Khalick & Lederman, 2000). With the tentative and changing feature (CT) of science being an important indicator about the quality of understanding scientific argumentation, as revealed in this study, will further promote discussions regarding whether to teach and to what extent to teach the tentativeness of science in science classrooms as discussed in previous studies (e.g., Lederman & O’Malley, 1990).

Research Question 4: Is there evidence that a group of secondary science teachers can apply some of the basic modern ideas of scientific argumentation after completing the online module?

Results from the pre- and post-surveys showed that ISSTs’ learning gains were oriented towards a positive view of modern perspectives on NOS, with improvements on a few of the item dimensions. After completing the online module, ISSTs achieved a better understanding that: a) SA is an important practice of science, b) science advances through the effort of a community of scientists, rather than individuals, and c) SA fosters science literacy through enhancing public understanding of science through the use of scientific language about socio-scientific issues. Likert items that included open-ended questions indicated that overall participants perceived this learning module positively. Most teachers thought that it improved
their understanding of SA and helped them visualize how SA could be included in the lesson planning process.

Additionally, results from follow-up interviews showed that they believed additional opportunities should include workshops to enhance the online learning experience. Among other aspects, these workshops could provide practical skills for facilitating SA in their classrooms, resources for various topics and places to find valid information. This is consistent with existing literature regarding professional development experiences among ISSTs. Sampson and Blanchard (2012) suggested that teacher educators should help teachers to gain a fundamental understanding of current practices of science. This included information on how to emphasize the importance and nature of SA in science learning, find resources they could use to integrate SA in classroom curricula, share strategies for generating argumentations, and address their concerns about implementing it into their classrooms. Although the online learning module used in this study focused on fostering teachers’ knowledge about the nature of SA, qualitative data collected in this study did highlight other aspects that ISSTs urgently need as mentioned by Sampson and Blanchard (2012).

Another result supported by existing literature (e.g., Sampson & Blanchard, 2012; Simon, Erduran, & Osborne, 2006) is that ISSTs emphasized the process of using valid evidence to support their claims or positions taken. Nevertheless, the focus of such processes varied across a spectrum of responses, from forming a valid claim, analyzing an existing claim, generating a conclusion, and finally to creating a model. Sampson and Blanchard (2012) found that many teachers in their study indicated the importance of using data to support their stances, but they had an inaccurate understanding of data in science. McNeil and Berland (2017) further criticized the lack of consensus in what counts as evidence in science classrooms, which resulted in
instructional practices focusing merely on teaching final forms of science ideas or disseminating information. Simon et al. (2006) found that teachers put emphasis on various aspects of argumentation depending on what they value and the designated goals of their instructional practice.

**Contextual Factors**

Participants in this study demonstrated a relatively informed understanding of NOS from a sociocultural perspective and scientific argumentation. There were several potential influential factors that may account for this predisposition. To begin with, this was a substantially homogeneous group. First, they had similar backgrounds. For instance, all participants held or were pursuing a post-graduate degree at the time of this study; among them, 11 held or were pursuing a master’s degree and two teachers were pursuing a doctoral degree. Eleven out of 13 participants had taught three or more years. Moreover, they represent a group of teachers who are experienced, so the study is clearly oriented toward relevance for in-service teacher education. The struggles these experienced teachers faced in further enhancing their understanding of NOS and SA indicate that less experienced teachers more than likely would also have challenges in comprehending some of the complexities of teaching SA. Furthermore, with respect to the context of this study, the political environment in the U.S. increasingly addresses issues of social class and social justice, where people are paying more attention to different cultures and diversity as it influences life in the nation. Therefore, issues of science and society may have been more prominent in the minds of the ISSTs before they began this study. Additionally, in recent decades science education has called for diversity and culturally responsive teaching within instructional practices to improve deep understanding of science and further promote science literacy (e.g., Mansour & Wegerif, 2013; Mensah, 2011, 2013). As
Mensah (2013) has argued, it is teachers who transform their practices and classrooms to help students engage fully in science, which would help students make decisions and act on social issues.

**Some Consistent Cross-cutting Results Within the Study**

Results in this study were consistent across the range of four research questions. In answering Research Question 1, the Likert inter-correlation diagram encompassed all 19 items included in the SEVs survey. This diagram provided evidence highlighting the richness of group cognition and coherence in ISSTs’ percepts regarding the epistemology and methodology perspectives of science. Such a coherent orientation may be expected among experienced, professionally prepared teachers especially if they are involved in further higher education in their profession. In Research Question 2, a significant statistical correlation was found between Argument and Counterargument, showing that ISSTs who generated informed argument also provided the well-informed counterargument. To find out how ISSTs’ understanding of NOS from a sociocultural perspective relates to their competency in generating SA, as hypothesized, one-tailed correlation analysis among five domains of SEVs survey and three components of SA showed that ISSTs who showed a strong understanding of the *invented and creative feature of science* (IC) generated informed Argument; and those with a strong understanding of the *changing and tentative feature of science* (CT) provided informed Counterargument. Furthermore, a correlation analysis (one-tailed) between five domains of SEVs and the total score of SA on the SSI items showed that the ISSTs with well-informed understanding of the *changing and tentative feature of science* (CT) generated informed scientific argumentation across all three components, in general. The statistically significant findings included in Research Question 1 and 2 further supported the results based on the inter-correlation network.
diagram, that there tends to be a considerable coherent and integrated set of results regarding teacher percepts and epistemological knowledge across different sources of evidence.

**Implications**

**Science teachers and instructional practices.** This study was undertaken to better inform our understanding of ISSTs’ existing understanding of NOS, especially to what extent it is concurrent with the latest theory and philosophical positions on the teaching of classroom science (such as in the NGSS); and hopefully will provide directions for future science teacher preparation programs from several aspects. First, how can we best organize teacher education programs to help teachers construct relatively modern views of the nature of science not only for existing teachers but also among future science teachers? Although this study focused on in-service teachers, it invites us to consider to what extent science teacher educators can effectively promote pre-service science teachers’ modern views of the nature of science? Among other innovative additions to science teacher education, providing pre-service and in-service science teachers with epistemic practices of science should be considered in relevant pre-service teacher preparation and in in-service teacher professional development programs. This should allow us to better assess to what extent teachers are able to effectively implement such practices in classrooms. A constructivist view of NOS would foster a more up-to-date understanding among teachers of the epistemological perspectives on the practices of science as emphasized in the NGSS. Also, it should provide a context for teachers to pay more attention to the processes of scientific discovery and the tentativeness of scientific knowledge. This is in contrast to the usual prevailing emphasis placed on the products of science. Thus, hopefully with a stronger understanding of NOS, teachers may be able to place more emphasis on the practices of science as well as the documentation of scientific discoveries.
Additionally, this study contributes to the already limited literature regarding professional development in argumentation (e.g., Duschl, 2007) and limited studies examining how teachers generate components of argumentation (Sampson & Blanchard, 2012). Scientific argumentation is an important topic in the current reform of science education. Furthermore, it represents the authenticity of science disciplines and “The thinking processes” within the community of scientists as they collectively develop new knowledge. From the in-service science teachers’ stance, based on multiple sources of published evidence, teachers prefer immersive experiences in professional development programs. This includes a more in-depth introduction to a theoretical background of why we should implement scientific argumentation and related practical skills in classroom professional teaching practice, and what resources are available to facilitate group argumentation in science classrooms.

**NOS and scientific argumentation of SSI.** This study contributes to the conversation regarding the relationship between scientific argumentation and NOS, especially from the standpoint of ISSTs. From a theoretical stance, teachers with a good understanding of NOS should better engage in SA as well; however, the evidence from empirical studies vary in support of this assumption. In this study, with a relatively consistent group of ISSTs, statistical significance was found between certain NOS domains and generated components of SA. This might indicate that not all features of NOS would directly contribute to, or are related to, a good understanding of SA. The invented and creative (IC), and changing and tentative (CT) features, of science, played important roles in relating NOS and components of SA. The latter feature especially reflects the sociocultural nature of the modern view of the development of science. Additionally, these two features are closely related, as the IC feature emphasizes the “Advancement” within science, and the CT feature focuses more on the “Social and
argumentative” characteristic of such “Advancement”. Socio-scientific issues provide a context where the nature of science (both knowledge and process aspects) can be linked to political, ethical and other social issues, thus enriching the science curriculum experience. Furthermore, scientific argumentation provides a tool through which learners can engage in the argumentative process in ways that are authentic for scientists.

**Limitations**

Though it serves the purpose of this study, the SEVs instrument (Tsai & Liu, 2005) was originally implemented and validated among students and teachers in Taiwan – an Asian site. The U.S. is a very different context (more diverse and likely more varied in scientific development); moreover, science is typically seen as a western product. Differences within the context of implementation may influence the findings if further studies of this kind are pursued. Meanwhile, with the goal of evaluating ISSTs’ current understanding of NOS from a social-cultural perspective, how ISSTs gained their NOS understandings was not examined in this study. Furthermore, one of the aims of this study, using mixed methods, was to elucidate in some detail aspects of ISSTs’ understandings of modern ideas of scientific inquiry. This was achieved partially by using a case-based approach where necessary (consistent with the sample size and composition of the participants) and drawing from interview data and other qualitative sources. While such an approach permits more rich and detailed analyses of individual participants in the study, the small sample size included in this study limits the degree of generalization that could be obtained with a much larger sample. However, as set forth in the opening paragraphs of this chapter, hopefully, this study with a more narrowly defined set of experienced, ISSTs can be used as a model for a more expanded research investigation. This includes improving some of
the instruments used and refining the methods when necessary to yield more robust statistical interpretations.

**Recommendations for Further Research**

Participants in this study were recruited from available local professional groups, who ultimately proved to be of rather similar professional and academic backgrounds, and thus more cohesive in terms of their perceptions of science and scientific argumentation than might be expected with a broader sample base. Selecting a more diverse group of science teachers, among cultural backgrounds and grade levels, would be beneficial to generalize the findings, and potentially could enable the researchers to explore gender differences, how teaching experiences influence their perceptions of NOS from a sociocultural perspective, and competence in generating scientific argumentation of SSI.

Also, future studies can examine evidence of pre-service science teachers’ understanding of NOS and competence in generating scientific argumentation of SSI; and how pre-service education may affect their broader professional development within this arena of NOS and SSI. A more substantial learning module, encompassing improvements based on the feedback from the current sample of teachers, should be created; and its influence examined on how well the prospective teachers develop more up-to-date understanding and coherent perceptions of the practice of scientific argumentation in science classrooms. Moreover, it would be beneficial to lead close examinations on how science teachers gain NOS understandings through related teacher education programs, reading related articles or documents, instructional practices, and professional development activities.
Conclusion

This mixed-methods study among 13 experienced in-service secondary science teachers in the northeastern area of the US showed that participants possessed a fairly advanced understanding regarding certain aspects of the nature of science (NOS) and scientific argumentation. Despite the existence of antipolar items in the Scientific Epistemological Views (SEVs) survey for assessing teachers’ NOS understanding, the network diagram analysis demonstrated that this group of science teachers perceived the epistemology and methodology perspectives of science in a cohesive way. Though most teachers were able to provide an argument, a counterargument, and a rebuttal, few of them generated a cohesive set of informed components of scientific argumentation. In addition, a one-tailed correlation analysis \((p < 0.05)\) among five domains SEVs survey and three categories of scientific argumentation showed that the invented and creative (IC) and changing and tentative (CT) features of science are significantly positively related to Argument and Counterargument components, respectively. It was found through another correlation analysis (one-tailed, \(p < 0.05\)) that the changing and tentative (CT) feature of science is significantly and positively related to the total score participants received in understanding scientific argumentation. Qualitative analysis of the semi-structured interviews and teachers’ written responses further confirmed such findings. In terms of the online learning module about scientific argumentation, descriptive analysis of data collected from pre- and post-surveys indicated good learning gains, despite relatively high scores on pre-test items. Among the teachers who were able to generate learning objectives after completing the online learning module, all of them emphasized students’ use of valid evidence to support claims, though the focus of lesson varied. Teachers reported preference towards relevant workshops providing them with practical techniques for facilitating scientific argumentation,
relevant resources for teaching scientific argumentation within various science disciplines, and information regarding where to find valid information. These findings are in line with the current sociocultural constructivism theory and efforts promoting understanding of the nature of science including sociocultural accounts and scientific argumentation about socio-scientific issues.
References


### Appendices

#### Appendix A


<table>
<thead>
<tr>
<th>Processes of inquiry</th>
<th>Science as cognitive-epistemic system</th>
<th>Science as a social-institutional system</th>
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<td>1</td>
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<tr>
<td>Aims and values</td>
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<td>Methods and methodological rules</td>
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*The Table in Irzik and Nola (2014, p. 1009) does not reference to ‘Institutional’. However the corresponding aspect discussed in their paper is “Social-Institutional System” as a section heading. Therefore we include the word ‘institutional’ in our reproduction of the Table.*
Appendix B

Questions for Collecting Participants’ Background Information

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<th>No.</th>
<th>Questions</th>
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| 1   | Your gender  
  o Male  
  o Female  
  o Prefer not to say |
| 2   | Your age  
  o 18-24  
  o 25-30  
  o 31-40  
  o 40 and more |
| 3   | Your ethnicity  
  o Caucasian  
  o American Indian or Alaskan Native  
  o Asian / Pacific Islander  
  o African American  
  o Hispanic  
  o Multiple ethnicity / Other (please specify) ____________________ |
| 4   | Highest degree you have achieved OR you are still pursuing  
  o High school or equivalent  
  o Bachelors’ or equivalent  
  o Masters’ or equivalent  
  o Doctorates’ or equivalent |
| 5   | Your undergraduate major (if applicable)  
  ____________________ |
| 6   | Your certification area (if applicable) (you can choose more than one option)  
  o Physics  
  o Chemistry  
  o Biology  
  o Earth science  
  o General science  
  o Other, please specify ____________________ |
| 7   | Grade levels you have taught or you are teaching (you can choose more than one option)  
  o Grade 5  
  o Grade 6  
  o Grade 7  
  o Grade 8 |
8 Subject(s) you have taught or you are teaching (you can choose more than one option)
   o Physics
   o Chemistry
   o Biology
   o Earth science
   o General science
   o Other, please specify __________

9 Years of teaching experiences
   o 0-2
   o 3-5
   o 6-10
   o 11-15
   o 15 and above

10 Have you previously participated in workshops or professional development events related to scientific argumentation?
   o No
   o Yes, please specify__________________________
Appendix C

Participant Demographics Matrix

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<th>Participant Gender</th>
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Total F= N= M=

Note. Eth = Ethnicity; Deg. = Highest Degree (includes obtained degree or degrees in process); Sub = Subjects Taught; Years = Years of Teaching Experience
Appendix D

The Instrument of Assessing Scientific Epistemological Views (SEVs) Survey
(Likert Scale from 1 – strongly disagree to 5 – strongly agree for each item)

The role of social negotiation (SN)
1. New scientific knowledge acquires its credibility through the recognition by many scientists in the field.
2. Scientists share some agreed perspectives and ways of conducting research.
3. The discussion, debates, and result sharing in science community is one major factor facilitating the growth of scientific knowledge.
4. Valid scientific knowledge requires the acknowledgement of scientists in relevant fields.
5. Contemporary scientists have agreed upon an acceptable set of standards with which to evaluate scientific findings.
6. Through the discussion and debates among scientists, the scientific theories become better.

The invented and creative nature of science (IC)
1. Scientists’ intuition plays an important role in the development of science.
2. Some accepted scientific knowledge comes from human’s dreams and hunches.
3. The development of scientific theories requires scientists’ imagination and creativity.
4. Creativity is important for the growth of scientific knowledge.

The theory-laden exploration (TL)
1. Scientists can make totally objective observations, which are not influenced by other factors. *
2. Scientists’ research activities will be affected by their existing theories.
3. The theories scientists hold do not have effects on the process of their exploration in science. *

The cultural impacts (CU)
1. People from different cultural groups have the same method of interpreting natural phenomena. *
2. Scientific knowledge is the same in various cultures. *
3. Different cultural groups have different ways of gaining knowledge about nature.

The changing and tentative feature of scientific knowledge (CT)
1. The development of science knowledge often involves the change of concepts.
2. Contemporary scientific knowledge provides tentative explanations for natural phenomena.
3. Currently accepted science knowledge may be changed or totally discarded in the future.

*presented in an empiricist-aligned (science provides the truths of the nature) or positivist-oriented perspective (scientific knowledge is always changing).
Appendix E

Protocols for follow up semi-structured interview

*Adopted from Tsai and Liu (2005)*

1. The role of social negotiations in science community (e.g., Do other scientists influence one scientist’s research work? Is science a process of individual exploration, mainly depending on personal efforts? How? How do scientists examine others’ research findings?)

2. The invented and creative nature of science (e.g., Do scientists “discover” or “invent” scientific knowledge? Why? How does creativity play a role in science?)

3. The theory-laden quality of scientific exploration (e.g., Does theory play a role on scientists’ exploration or observations? How? Do scientists have any expectation before conducting the exploration? Why?)

4. The cultural impacts on science (e.g., Do different cultural groups of people have different types of “science”? How? Does culture influence the development of scientific knowledge? How?)

5. The changing and tentative feature of science knowledge (e.g., After scientists have developed a theory, does the theory ever change? Does the development of scientific knowledge involve the change of concepts? How?)
Scenario – Global Warming

Global warming is a major environmental issue facing the international community. According to the majority of scientists, human activities, especially the burning of fossil fuels (oil, gas, and coal) has significantly increased the levels of carbon dioxide and other greenhouse gases in atmosphere. These gases trap solar energy, which raises the earth’s temperature, and this will in turn lead to an environmental catastrophe.

According to the opposition group of scientists, the influence of humans is insignificant since the increases in temperature are a natural part of the earth’s climate as evidenced by the changes in temperature as alternating ice ages and warmer periods. This group worries that proposed ‘solutions’ to global warming will have devastating effects on the global economy.

In 1997, there was a climate conference in Kyoto, Japan, where more than 160 nations met to discuss binding limitations on greenhouse gases. The outcome of the meeting was the Kyoto Protocol, which obliged developed countries (e.g., US) to commit to reduce their global emissions by 5.2% by 2012. Developing countries (e.g., Lebanon) were exempted from any legally binding commitment but were encouraged to reduce their emissions by providing them with the necessary financial and technical support. So far, about 140 countries agreed to abide by the Kyoto Protocol. The United States did not agree to abide by the Kyoto Protocol although it is one of the main emitters of greenhouse gases that contribute to global warming. As noted, the Kyoto Protocol does not require fast-growing developing countries (e.g., China and India), who are also becoming major polluters, to reduce their greenhouse gas emissions. The Kingdom of Saudi Arabia ratified the Kyoto Protocol in 2005.

(a) Do you think that your country should have joined the Kyoto Protocol?
   YES                                 NO                                          NOT SURE
(b) Do you think that your country should agree to be legally responsible for limiting greenhouse gas emissions and keeping it stable? Explain and justify your decision.
(c) Another scientist, Professor Ponso, disagrees with your decision. How could he explain his position to illustrate the reasons supporting it and convince you?
(d) What would you reply to Professor Ponso to explain that your decision is right?
(e) How can you explain that scientists reached different conclusions even though they were all looking at the same data about the possible outcomes of global warming?
(f) Do you think the knowledge about global warming might change in the future? Explain why or why not.
(g) Do you think you might change your decision in the future? Explain why or why not.
(h) Is there anything else you would want to know about this issue that might help you decide or even change your decision?
Appendix G

Semi-structured Interview Questions for Scientific Argumentation about SSI

1. Can you explain and elaborate on your response to questions # (b-h)?

2. What did you mean by saying [response]?

3. You referred [response] the question #, how do you think it support your claim that your country should/should not have joined the Kyoto Protocol?

4. The example [response] you provided in question #, can you explain more on it?

5. Can you provide an example to explain what you mean by saying [response]?
Appendix H

A Topic Summary of the Online Learning Module about Scientific Argumentation

Title of Module
SCIENTIFIC ARGUMENTATION

Introduction
Overview of the organization of the module and instructions about navigating interactions.
There are two main parts included in the module:
Part I: Why pay attention to scientific argumentation?
Part II: Where does scientific argumentation fit in the most recent education reform movement?

Part I: Why pay attention to scientific argumentation?
This part describes:
  a) The definition of scientific argumentation, how it is related to science education and an example of scientific argumentation.
  b) Then four main reasons for paying attention to scientific argumentation are provided:
     a. scientific argumentation is part of science.
     b. scientific argumentation is of critical importance to science education.
     c. scientific argumentation is critical for understanding the nature of science.
     d. scientific argumentation is an important process to promote science literacy.

Part II: Where does scientific argumentation fit in the most recent education reform movement?
This part describes where scientific argumentation fits in the most recent reform in science education.
Appendix I

Pre-test Survey Questions

Pre-test Introduction
Please choose the response that most appropriately describes your opinion.

<table>
<thead>
<tr>
<th>Items</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neither Agree or Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. During scientific argumentation, people use scientific language such as claim, evidence, warrants, counter arguments etc. to organize their points of view. Sometimes, two or more people will each take a position of approving or disapproving a scientific conclusion and try to persuade each other.</td>
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<tr>
<td>2. Science educators pay attention to scientific argumentation as it helps students to gain a deep understanding of scientific knowledge and how science is developed, including improving students’ understanding of the language of science.</td>
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<td>3. Scientific argumentation is an important current idea in teaching science, but it has not been emphasized in the Next Generation of Science Standards, because it is not one of the important practices of science.</td>
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<td>4. The development of science largely progresses due to revolutionary ideas, often by one person, not the result of a community of scientists.</td>
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<td>5. Scientific argumentation can foster science literacy through enhancing public understanding of science; thus, enabling use of scientific language about socio-scientific issues.</td>
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</table>
Appendix J

Post-test Survey Questions

Post-test Introduction
Please choose the response that most appropriately describes your opinion after experiencing the online module. You are allowed to review the online module if you believe it will help you to demonstrate your understanding.

<table>
<thead>
<tr>
<th>Items</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neither Agree or Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. During scientific argumentation, people use scientific language such as claim, evidence, warrants, counter arguments etc. to organize their point of view. Sometimes, two or more people will each take a position of approving or disapproving a scientific conclusion and try to persuade each other.</td>
<td></td>
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<tr>
<td>2. Science educators pay attention to scientific argumentation as it helps students to gain a deep understanding of scientific knowledge and how science is developed, including improving students’ understanding of the language of science.</td>
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<tr>
<td>3. Scientific argumentation is an important current idea in teaching science, but it has not been emphasized in the Next Generation of Science Standards, because it is not one of the important practices of science.</td>
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<tr>
<td>4. The development of science largely progresses due to revolutionary ideas, often by one person, not the result of a community of scientists.</td>
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<td>5. Scientific argumentation can foster science literacy through enhancing public understanding of science; thus enabling use of scientific language about socio-scientific issues.</td>
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<td>Items</td>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Neither Agree or Disagree</td>
<td>Agree</td>
<td>Strongly Agree</td>
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<tr>
<td>6. This online learning module helps me to gain a deeper understanding of scientific argumentation.</td>
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<tr>
<td>Please explain your response in detail in terms of how this online module have improved your knowledge regarding scientific argumentation:</td>
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<td>7. After going through this online module, I can see how scientific argumentation can be used in lesson planning.</td>
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<tr>
<td>Please explain your response as much as possible.</td>
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<td>8. This online module can help me with my lesson planning regarding scientific argumentation.</td>
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<tr>
<td>Please explain your response regarding lesson planning.</td>
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<td>9. This online module would allow me to teach scientific argumentation based on what I learned.</td>
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<tr>
<td>Please explain your response regarding applying the information you have learned:</td>
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</table>
10. Could you write learning objectives for a lesson that you may implement with scientific argumentation based on what you have learned from this online module?

Mark your response, Yes or No. If “Yes” please write an example of an objective you would use.

| Yes [ ] | No [ ] |
Appendix K

Follow up Interview Questions for the Online Learning Module

1. How do you like the learning module?

2. What do you like about this learning module?

3. What suggestions you will give to improve this learning module?

4. If you were to attend a workshop focusing on scientific argumentation, what would you expect to gain from it?
## SSI Item – Global Warming Questionnaire Items and Their Purposes

<table>
<thead>
<tr>
<th>Questions</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Do you think that your country should have joined the Kyoto Protocol? YES NO NOT SURE</td>
<td>To have respondents make decisions</td>
</tr>
<tr>
<td>(b) Do you think that your country should agree to be legally responsible for limiting greenhouse gas emissions and keeping it stable? Explain and justify your decision.</td>
<td>To find out about respondents’ skills in generating arguments</td>
</tr>
<tr>
<td>(c) Another scientist, Professor Ponso, disagrees with your decision. How could he explain his position to illustrate the reasons supporting it and convince you?</td>
<td>To find out about respondents’ skills in generating counterarguments</td>
</tr>
<tr>
<td>(d) What would you reply to Professor Ponso to explain that your decision is right?</td>
<td>To find out about respondents’ skills in generating rebuttals</td>
</tr>
<tr>
<td>(e) How can you explain that scientists reached different conclusions even though they were all looking at the same data about the possible outcomes of global warming?</td>
<td>To assess respondents’ views about the subjective aspect of NOS</td>
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<tr>
<td>(f) Do you think the knowledge about global warming might change in the future? Explain why or why not.</td>
<td>To assess respondents’ views about the tentative and empirical aspects of NOS</td>
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<tr>
<td>(g) Do you think you might change your decision in the future? Explain why or why not.</td>
<td>To assess respondents’ views about the tentative and empirical aspects of NOS</td>
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<tr>
<td>(h) Is there anything else you would want to know about this issue that might help you decide or even change your decision?</td>
<td>To assess respondents’ views about the empirical aspect of NOS</td>
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Appendix M

Coding Rubric for the SSI Item

Examples of responses to Global Warming scenario related to argumentation skills

<table>
<thead>
<tr>
<th>Argumentation Component</th>
<th>Naive (Score = 1)</th>
<th>Intermediary (Score = 2)</th>
<th>Informed (Score = 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Argument</strong></td>
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<tr>
<td>Yes. The US is a powerful country and can set an example for other countries. The scientific evidence supports this course of action. (T12, Item b)</td>
<td>Yes. As a major contributor to greenhouse gas emissions, the United States has a global responsibility. (T5, Item b)</td>
<td>Yes. Global warming is one of the great existential threats facing humanity. The earlier that actions are taken, the greater an impact they will have. More modest actions now will be more effective than even more drastic action at a later time. (T3, Item b)</td>
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<td><strong>Counterargument</strong></td>
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<td>I would need to see data taken around the world for many years to convince me that I am incorrect. (T1, Item c)</td>
<td>Professor Ponso could show me another time period where greenhouse gases increase, but then decreased again. (T6, Item c)</td>
<td>If Professor Ponso had scientific data showing that burning fossil fuels do not produce CO2 emissions; that CO2 and other greenhouse gases do not warm up the Earth’s oceans; that the warming of the oceans is not having a deleterious [effect]. (T9, Item c)</td>
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<td><strong>Rebuttals</strong></td>
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<tr>
<td>I would cite scientific data from peer-reviewed journals that support</td>
<td>I would show Professor Ponso evidence, such as ocean warming, and back my claims with citations that humans</td>
<td>I would use data to show him the impact of United States is having on greenhouse gases. And data to show viable</td>
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<tr>
<td>my claim.</td>
<td>(T9,</td>
<td>Item d)</td>
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<tr>
<td>alternatives to</td>
<td>(T5,</td>
<td>fossils fuels and the positive impacts they could have on the</td>
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<td>are a major</td>
<td>Item d)</td>
<td>economy and work ecology.</td>
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Note: *All participants provided at least one sound reasons as an argument.*