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SCIENCE TEACHERS' EPISTEMOLOGICAL BELIEFS, PCK of ARGUMENTATION, and IMPLEMENTATION: AN EXPLORATORY STUDY

Ozden Sengul

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This dissertation, SCIENCE TEACHERS' EPISTEMOLOGICAL BELIEFS, PCK of ARGUMENTATION, and IMPLEMENTATION: AN EXPLORATORY STUDY, by OZDEN SENGUL, was prepared under the direction of the candidate's Dissertation Advisory Committee. It is accepted by the committee members in partial fulfillment of the requirements for the degree, Doctor of Philosophy, in the College of Education and Human Development, Georgia State University.

The Dissertation Advisory Committee and the student's Department Chairperson, as representatives of the faculty, certify that this dissertation has met all standards of excellence and scholarship as determined by the faculty.

Renee S. Schwartz, Ph.D
Committee Chair

Patrick J. Enderle, Ph.D
Committee Member

Maggie D. Renken, Ph.D
Committee Member

Janice B. Fournillier, Ph.D
Committee Member

Date

Gentrude Ticker Sachs, Ph.D
Chairperson, Middle and Secondary Education

Paul A. Alberto, Ph.D
Dean
College of Education and Human Development

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Ozden Sengul
Department of Middle of Secondary Education
College of Education and Human Development
Georgia State University

The director of this dissertation is:

Dr. Renee S. Schwartz
Department of Middle and Secondary Education
College of Education and Human Development
Georgia State University
Atlanta, GA 30303

CURRICULUM VITAE

Ozden Sengul

ADDRESS:

Department of Middle and Secondary Education
Atlanta, GA, 30303

EDUCATION:

Ph.D.	2018	Georgia State University Middle and Secondary Education, Science Education
Masters Degree	2012	University of Tokyo Physics
Bachelors Degree	2008	Bogazici University Integrated B.S. and M.S. Program in Teaching Physics

PROFESSIONAL EXPERIENCE:

Fall 2016 – Spring 2017	<i>Graduate Research Assistant</i> Department of Middle and Secondary Education Georgia State University
Fall 2013 – Spring 2016	<i>Graduate Teaching Assistant</i> Department of Physics and Astronomy Georgia State University
Spring 2014 – Spring 2016	<i>Graduate Research Assistant</i> Department of Physics and Astronomy Georgia State University
Fall 2013	<i>Graduate Research Assistant</i> Department of Middle and Secondary Education Georgia State University
2009 - 2012	<i>Graduate Research Assistant</i> University of Tokyo

PUBLICATIONS:

Enderle, P., **Sengul, O.**, Koulagna, Y., Grooms, J., & Sampson, V. (Submitted). How implementing and refining an argumentation instructional model can shape science teacher beliefs. *Science Education*.

Von Korff, J., Smith, M., Smith, A. M., Kiepora, L., and **Sengul, O.** (Submitted). Student-centeredness is context-dependent: Barriers encountered by Learning Assistants in SCALE-UP classroom. *Physical Review special topics- Physics Education Research*.

Sengul, O. (Submitted). Professional development design to promote change in undergraduate physics teaching. *To Improve the Academy*.

Sengul, O., & Schwartz, S. R. (in preparation). *Embedding science and engineering practices into 5E instructional model while teaching physics: Reflective journey*. To be submitted to "Journal of College Science Teaching."

Sengul, O. , Schwartz, S. R., & Enderle, P. (in preparation). *Democratic Science Education, Scientific Literacy, and Scientific Argumentation*. To be submitted to "Science Education."

PRESENTATIONS

Schwartz, S. R., Enderle, J. P., & **Sengul, O.** (2018, March). *Developing Middle School Science Teachers' Views of NOS and PCK for Argumentation*. Paper accepted to present at the meeting of National Association for Research in Science Teaching (NARST), Atlanta, GA

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Sengul, O. (2017, April). *Practicing teachers' challenges in integrating argumentation into science instruction: A meta-synthesis*. Paper accepted to present at the meeting of the American Educational Research Association (AERA), San Antonio, TX.

Enderle, P., **Sengul, O.**, Koulagna, Y., Grooms, J., & Sampson, V. (2017, April). *The impact of implementing and refining an argumentation instructional model on science teachers' beliefs*. Paper accepted to present at the meeting of National Association for Research in Science Teaching (NARST), San Antonio, TX.

Sengul, O. & Von Korff, J. (2017, February). *Students' engagement in argumentation while working on physics tutorials*. Paper presented at the winter meeting of American Association of Physics Teachers (AAPT), Atlanta, GA.

Sengul, O., & Schwartz, R. (2016, April). *Planning Instruction by Implementing 5E Model into an Undergraduate Physics Laboratory: Action Research Study*. Paper presented at the meeting of National Association for Research in Science Teaching (NARST), Baltimore, MD.

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**SCIENCE TEACHERS' EPISTEMOLOGICAL BELIEFS, PCK of ARGUMENTATION,
and IMPLEMENTATION: AN EXPLORATORY STUDY**

by

OZDEN SENGUL

Under the Direction of Assoc. Prof. Renee S. Schwartz

ABSTRACT

The research efforts call for students' and teachers' engagement in argumentation as the core epistemic practice of science to promote their participation in cognitive, epistemic, and social aspects of scientific thinking and reasoning and support their understanding of how knowledge is developed in the scientific community. Science teachers' pedagogical content knowledge (PCK) of argumentation, epistemological beliefs, and personal or external factors may influence how they integrated argumentation instruction. The present study had a qualitative multiple case study design and explored the influence of a one-year professional development program on four urban in-service science teachers' PCK of argumentation and epistemological beliefs. The study also examined how science teachers translated their knowledge and beliefs into practice, and what other factors mediated the argumentation instruction. The data was collected through questionnaires, classroom observations, teacher created artifacts, field notes, informal conversations, and semi-structured interviews. The data was analyzed through constant comparative method to develop an in-depth profile of participants and to identify the shifts in science teachers' epistemological beliefs and PCK of argumentation and the relationship between these constructs.

The findings indicated that the positive change in the participating teachers' PCK of argumentation was apparent during the informal conversations and final interview. The teachers held consistent and mixed epistemological beliefs throughout the study even though there were slight positive or negative shifts. These teachers' implementation of argumentation was either aligned or modified with the expectations of argumentation instructional model in parallel to their PCK of argumentation and epistemological beliefs. For example, the teacher, who held high-quality PCK of argumentation, had evaluativist beliefs about nature of knowledge and high-quality argumentation instruction. Another teacher, who held high-quality PCK of argumentation by the end of the study, had multiplist beliefs about nature of knowledge and low-quality argumentation instruction. Moreover, participating teachers referred to the factors mediating the argumentation instruction as their beliefs about student ability, district and standards, curriculum and testing, and school context. These results made recommendations for the design of professional development efforts targeting teachers' PCK of argumentation and epistemological beliefs to result in significant changes.

INDEX WORDS: Pedagogical content knowledge of argumentation, epistemological beliefs, argumentation instruction, science teacher, in-service

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IMPLEMENTATION: AN EXPLORATORY STUDY

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CHAPTER I

INTRODUCTION

The essential goal of science education is to help learners become scientifically literate individuals (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 2012). The recent emphasis on scientific literacy focuses on more than understanding and applying scientific concepts and requires “integration of science concepts and processes, metacognitive processes, critical reasoning skills, and cultural aspects of science (e.g., the epistemic nature of science)” (Cavagnetto, 2010, p. 337). For more than 100 years, national and international science education reform documents (e.g., Australian Curriculum, Assessment, and Reporting Authority [ACARA], 2012; National Research Council [NRC], 2012; U.K. Department for Children, Schools, and Families [DCSF], 2009) have advocated scientific practices and aspects of nature of science as important educational objectives for scientific literacy (Lederman & Lederman, 2014). NOS has been described as “science as a way of knowing or the values and beliefs inherent to scientific knowledge and its development” (Lederman, 2007, p. 833). Scientific practices address the processes that involve asking questions, collecting and analyzing data, engaging in argument from evidence, and communicating and justifying results as well as require the identification of assumptions and alternative explanations and the use of logical thinking (Ford, 2015; Lederman & Lederman, 2014; NRC, 2012). Understanding these aspects and processes of science helps students figure out the solutions to scientific problems and enhance their engagement in meaningful experiences such as questioning, exploration, and guidance.

Social constructivist theories define learning as “a product of a process of deliberate and discursive interactions with others— interactions which then enable the individual to construct new understandings and mental models of the world” (Falk et al., 2012, p. 37). These theories approach learning as both an individual and a social process, in which people construct knowledge through expanding the existing ideas with new experiences and exchanging them with other people (Sampson, Enderle, Grooms, & Witte, 2013). This perspective of learning supports students in developing practices and abilities to understand the NOS and scientific processes, communicate the information, and make connections to science, technology, and society (Jiménez-Aleixandre & Crujeiras, 2017). In other words, learners can engage in construction, critique, and justification of knowledge claims as the practices of a scientific community (Berland et al., 2016) that can support students to have a functional understanding of how the science content develops and the ability to make informed decisions about science-related issues.

Across the world, many countries promote the incorporation of scientific argumentation in the process of teaching and learning science as a significant component of scientific literacy (Cavagnetto, 2010; Duschl, 2008; Jiménez-Aleixandre & Crujeiras, 2017). A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (NRC, 2012) called for students’ and teachers’ engagement in argumentation as the core epistemic practice of science to promote students’ participation in cognitive, epistemic, and social aspects of scientific thinking and reasoning and to support their understanding of how knowledge is developed and communicated to the scientific community (Duschl, 2008; Jimenez-Aleixandre & Erduran, 2008; Osborne, 2010). “Argument” and “argumentation” constructs have been defined differently in science education literature. The former is considered as the product, in which an artifact is

created to “articulate and justify claims or explanations” (Sampson & Clark, 2008, p. 448).

“Argumentation” as a scientific practice is emphasized by national and international organizations as a dialogic process (e. g. ACARA, 2012; Cavagnetto, 2010; NRC, 2012), which involves the acts of construction, critique, persuasion, and revision of the knowledge claims as well as supports the learners’ enculturation into the practices of science community (Manz, 2015). Addressing not only the structural elements but also the dialogic aspect of argumentation helps science teachers to move beyond the cognitive dimension to design instructional resources around social and epistemic dimensions of science teaching and learning.

Various research-based curriculum materials (McNeill & Krajcik, 2012), instructional models (Sampson, Grooms, & Walker, 2011; Wallace, Hand, & Yang, 2004), and instructional strategies (Simon, Erduran, & Osborne, 2006) have been developed to support science teachers’ explicit argumentation instruction. These resources aim to help teachers move away from the traditional science instruction and create classroom environments conducive to argumentation as a core scientific practice. As an example, González-Howard and colleagues (2015) suggest that teachers may discuss the meaning of the word or phrase related to argumentation, do a think-aloud to model appropriate language during a task, and simplify a complicated claim by identifying fundamental concepts. Researchers also think integrating small tasks to promote argumentation such as competing theories (Osborne, Erduran, & Simon, 2004) or discrepant events (Sampson & Clark, 2009). They also use modeling how to provide evidence and reasoning, open-ended questions, think-pair-share or jigsaw activities, or laboratory investigations for the small group or whole class discussions (Choi, Klein, & Hershberger, 2015; McNeill & Pimentel, 2010).

Wallace and colleagues (2004) propose Science Writing Heuristics (SWH) approach as a template to support students' participation in collaborative laboratory investigations and promote their argumentative writing and talk to enhance students' knowledge of science content. SWH approach aims to enhance not only student voice and scientific argumentation but also the teacher voice and questioning. Sampson and colleagues (2011) design Argument-Driven Inquiry (ADI) model to assist teachers in promoting scientific argumentation through addressing the social and material aspect of science as a whole rather than separate learning goals to construct and refine knowledge claims. This instructional model supports students' engagement in the scientific practices and aspects of NOS through developing a method and data collection and analysis, construction of an argument, argumentative writing, and social interaction and discourse to evaluate alternative ideas and reach a consensus. McNeill and Krajcik (2008) utilize "Investigating and Questioning Our World Through Science and Technology (IQWST)" curriculum materials addressing scientific explanation framework to suggest teachers introduce and model the use of argumentation, make connections to an everyday example, and make the rationale for scientific explanation explicit in classroom instruction.

These instructional supports aim to create a fundamental pedagogical shift in science teachers' teaching approaches from knowledge transmission to knowledge construction, to teaching critical thinking and scientific reasoning, and to enhancing students' knowledge of and experiences with scientific practices. However, teachers may have challenges in addressing both structural elements and dialogic interactions through written and oral argumentation due to their focus on lecturing and content coverage as well as lack of pedagogical strategies (McNeill, González-Howard, Katsh-Singer, & Loper, 2016; McNeill & Berland, 2017). They may struggle with providing relevant evidence and reasoning in their arguments (Sampson & Blanchard, 2012;

McNeill & Knight, 2013). They have challenges in promoting accountable talk and allowing students to construct and defend knowledge claims as well as critique and elaborate on each other's ideas (Alozie, Moje, & Krajcik, 2010; Osborne, Simon, Christodoulou, Howell-Richardson, & Richardson, 2013). Research studies (Pimentel & McNeill, 2013; Osborne et al., 2013) make a case for teachers' lack of knowledge about argumentation, which may influence their lesson planning, the enactment of course materials, and the evaluation of students' arguments around structural elements and dialogic aspects. Teachers need to develop knowledge of students' learning experiences through argumentation including their successes and challenges as well as knowledge of appropriate instructional strategies in written or oral tasks to support students' learning and critical thinking as well as to accommodate students' learning needs.

An area of research focuses on the ways to support teachers' pedagogical content knowledge (PCK) of scientific argumentation (Knight-Bardsley & McNeill, 2016; McNeill et al., 2016; Zembal-Saul, 2009). Pedagogical content knowledge (PCK) is a component of teacher professional knowledge that is "a knowledge base used in planning for and the delivery of topic-specific instruction in a very specific classroom context, and as a skill involved in the act of teaching" (Gess-Newsome, 2015, p. 30). Shulman (1986) introduces the idea of PCK when he criticizes that subject matter knowledge is prerequisite knowledge for teaching, and the methods play a secondary role for the qualification and effectiveness of a teacher. Shulman suggested that teachers' professional knowledge base involves the knowledge of content and pedagogy around different knowledge dimensions and contributes to teachers' practices in a particular classroom context.

Shulman's ideas have been interpreted differently and evolved to other PCK models as alternative approaches. For example, Magnusson, Krajcik, and Borko (1999) conceptualize science teachers' PCK for science topics in five dimensions: orientations toward science teaching,

knowledge about science curriculum, knowledge about students' understanding of specific science topics, knowledge about assessment in science, and knowledge about instructional strategies for teaching science. Two components of these knowledge dimensions, knowledge of students' conceptions and knowledge of instructional strategies, are the areas that require greater support for teachers' development (Kind, 2009). This study will focus on science teachers' PCK of argumentation around knowledge of student conceptions and instructional strategies.

Ford (2008) argues that epistemic and logistic authority of the teacher should create a classroom community where students can make sense of data through making connections between facts, methods, and values, construct explanations and alternative interpretations, and evaluate, justify, and critique knowledge claims. Teachers should emphasize how and why argumentation are employed in scientific and classroom communities rather than engaging in pseudo-argumentation (Berland et al., 2016; Ford, 2008). Teachers need to be aware of students' challenges in the process of argumentation. For example, students may struggle in justifying their claims, understanding the difference between data and evidence, and providing backing or reasoning to support their evidence (Sampson et al., 2013; McNeill & Krajcik, 2008). Science teachers have a responsibility to incorporate appropriate instructional practices to address these challenges, which may enable students to engage in the scientific practices such as designing scientific experiments, collecting and analyzing data, generating explanations, scaffolding, and modeling.

Science teachers' PCK of argumentation may or may not be translated into instructional practices. They may develop a keen understanding of structural elements of an argument, but fail to turn their knowledge into practice; or they may fail to evaluate how students supported their claims with evidence and asked appropriate questions (McNeill & Knight, 2013). Personal factors (e.g.,

teacher beliefs) or external factors (e.g., policies, standards, or curriculum) may influence “what a teacher knows, how knowledge may or may not be used” (Gess-Newsome, 2015, p. 35). According to Gess-Newsome (2015), teacher beliefs may act as an amplifier, filter, or guide for teacher learning of argumentation and classroom instruction. For instance, teachers may know what claim, evidence, and reasoning mean and how to promote dialogic discourse with appropriate methods addressing student conceptions. However, they may resist to incorporating their knowledge into practice because their beliefs about science teaching as telling may act as a filter for argumentation instruction. On the other hand, teachers’ beliefs about nature of knowledge as construction may foster a change in their teacher-centered practice and promote teachers’ planning and decisions about classroom behaviors around science and engineering practices, disciplinary core ideas, crosscutting concepts, and characteristics of science.

There is a complex and dynamic interaction between teacher knowledge, beliefs, and practices, which may have a variety of implications for teachers working in different contexts. The arguments about the relationship between teacher knowledge, beliefs, and practices raise the questions whether teacher knowledge or beliefs change to shift the pedagogical practices or teacher practices change to reform teachers’ knowledge and beliefs. An area of research also focuses on exploring teacher beliefs to understand its relationship to teacher knowledge and instructional practices. Kagan (1992) argues that the evolution of the instructional strategies, learning tasks, and teacher practices are mediated by teachers’ epistemological beliefs. Epistemology is concerned with the study of knowledge and defined differently in philosophy and psychology (Sandoval, 2005). Psychologists define epistemology as personal epistemology to address individuals’ set of general beliefs about the nature of knowledge and knowing, “how knowledge is constructed, how knowledge is evaluated, where knowledge resides, and how

knowing occurs” (Hofer, 2004, p. 4). In philosophy, epistemology is concerned with the conditions to acquire the knowledge and refers to “the origin, nature, limits, methods, and justification of human knowledge” (Hofer, 2004, p.4). Epistemological beliefs have been considered as relatively stable contents of cognition (Sinatra, 2016) and studied using different labels such as “personal epistemology” (Hofer, 2004), “epistemological thinking” (Kuhn & Weinstock, 2002), and “epistemic beliefs” (Muis, 2007). These different terms will be used interchangeably in the current study to address epistemological beliefs.

Educational researchers (e.g., Kuhn, 1991; Schommer, 1990; Perry, 1970) have studied epistemological beliefs with either developmental or multidimensional approach. The former refers to epistemology as unidimensional and ranging from objectivist stance to multiplist or evaluativist stance (Muis, 2007), whereas the latter addresses epistemological beliefs as more or less independent dimensions about various aspects of knowledge in different levels of sophistication (Hofer, 2004). Multidimensional approaches to epistemological beliefs have been categorized as beliefs about nature of knowledge to address individuals’ beliefs about certainty or simplicity of knowledge and beliefs about nature of knowing or learning to refer to the process of knowing and controlling and influencing factors in the learning process (Buehl, 2008). This study will approach epistemological beliefs with a multidimensional approach involving more or less independent, but related dimensions in different levels of sophistication.

Empirical evidence also shows that people possess both domain-general and domain-specific epistemological beliefs that are separate from, but intimately intertwined with each other (Muis, Bendixen, & Haerle, 2006). Domain-specific epistemological beliefs were defined as specific to academic disciplines such as hard-domains (well-defined) as epistemological beliefs about science or physics or soft- domains (ill-defined) as epistemological beliefs about history or social studies (Chai, Khine, & Teo, 2006; Hofer, 2000). In science education, two overlapping

constructs define learners' epistemological beliefs about science and scientific knowledge as domain-specific epistemological beliefs: knowledge about nature of science (NOS) and scientific epistemological beliefs (SEBs) (McDonald, 2016). From a philosophical perspective, Lederman and Lederman (2014) defined nature of science (NOS) as the characteristics of scientific knowledge including tentativeness, empirical-embeddedness, and sociocultural aspects, which develop through the knowledge construction processes such as scientific inquiry or scientific practices. However, Wu and Tsai (2011) defined scientific epistemological beliefs (SEBs) from a psychological perspective as the beliefs about the nature of scientific knowledge and the nature of knowing science (McDonald, 2016). The terms "scientific epistemological beliefs" and "knowledge of nature of science" are utilized as different epistemological approaches in science education literature, and in the present study, these terms will be examined and considered as science teachers' domain-specific epistemological beliefs.

Research studies have mostly focused on the relationship between teachers' beliefs, knowledge, and practices of teaching and learning (Chen, Morris, & Mansour, 2014; Capps & Crawford, 2013; Mansour, 2013). However, an epistemological focus would be helpful to generate insights into science teachers' epistemological beliefs (hereafter referred to both domain-general and domain-specific) that may change through engaging in and enacting scientific practices, particularly argumentation. An understanding of teachers' epistemological beliefs is a significant aspect of understanding whether or not their epistemological beliefs are related to teachers' PCK of argumentation and translated into the instructional practices. The current science education literature lacks empirical evidence about teachers' epistemological beliefs, PCK of argumentation, and instructional practices in a single study. A study on teacher epistemology is needed to understand how professional

development programs influence teachers' PCK of argumentation, epistemological beliefs, and their effectiveness on explicit argumentation instruction.

Statement of the Problem

The research efforts suggest that science teachers should enculturate students into the practices of scientific community and develop their knowledge and ability about the epistemic nature of science (Cavagnetto, 2010; Duschl, 2008; Jimenez-Aleixandre & Crujeiras, 2017; NRC, 2012). Despite the higher emphasis on national and international documents (e.g. ACARA, 2009; NRC, 2012) and the development of curriculum materials and instructional models and strategies (e.g. McNeill & Krajcik, 2012; Sampson et al., 2011; Simon et al., 2006), argumentation has rarely been utilized as an effective strategy to improve the learners' views of NOS (McDonald, 2010, 2016; Pimentel & McNeill, 2013). Teachers' views of science as a body of knowledge result in the transmission of scientific facts and encourage students to memorize the scientific ideas and reflect the inaccurate beliefs about the nature of science. Instead, science teaching should focus on the evolving nature of science and foster students' engagement in the epistemological basis of this scientific practice such as exploration, construction, critique, evaluation, and refinement of scientific ideas.

Effective teaching requires a shift from viewing science teaching as merely the knowledge of content and general pedagogical practices (Evagorou & Dillon, 2011; Kind, 2009) to the integration of content and pedagogy into an understanding and representation of particular topics, problems, or strategies to diverse learners during instruction (Shulman, 1987). To incorporate argumentation efficiently, teachers need to develop PCK of argumentation involving knowledge of students' learning difficulties and the instructional approaches to address these challenges about structural and dialogic aspects of argumentation and enhance students' active participation in knowledge construction around argumentation activities. For example, teachers may model the development and critique of alternative claims with relevant evidence and justification in a small group or whole class

discussions (Choi et al., 2015; McNeill & Knight, 2013; Simon et al., 2006). They can use argumentation while teaching different modes of inquiry (Gray & Kang, 2014) as well as to support the development of academic language through argumentative writing or talk (Swanson, Bianchini, & Lee, 2014).

Scientists engage in a dialect of construction and critique of claims to produce reliable scientific knowledge (Ford, 2008a, b). Similarly, students who participate in argumentation can construct knowledge of the natural world through the application of the epistemological understandings of nature of science (Jimenez-Aleixandre & Crujeiras, 2017; McDonald, 2016; Sandoval, 2014). This practice may be linked to improved critical thinking, communication, and reasoning skills as well as to access scientific ways of knowing, thinking, and acting (Manz, 2015; Pimentel & McNeill, 2013). Therefore, science teachers should be aware of different thinking patterns and strategies and use epistemologically-oriented class activities. In this way, they can enhance students' capacities to understand the processes of scientific inquiry, work in groups, articulate their thinking towards developing critical thinking skills and addressing the use of evidence to support claims, make comparisons, critique, and solve complex problems.

Professional development (PD) programs, educative curriculum materials or science methods courses aim to improve teachers' knowledge, skills, and teaching practices as well as their students' learning outcomes around argumentation (Capps, Crawford, & Constanas, 2012; Knight-Bardsley & McNeill, 2016). Through these opportunities, science teachers may or may not learn how to design learning tasks to incorporate argumentation into instruction as well as to learn how to scaffold and model the thinking and reasoning processes such as the construction, critique, and evaluation of knowledge claims. Empirical evidence from Knight-Bardsley and McNeill (2016) and Marco-Bujosa et al. (2017) indicate that intensive and continuous help through PD programs and educative curriculum materials may develop strong PCK of argumentation, but fail to align their practices with

the suggestions from the program to promote argumentation instruction. The findings of these recent studies indicate a gap in the literature, which explicitly refer to teachers' developing a keen understanding of structural and dialogic aspects of argumentation around student conceptions and instructional strategies as well as translating their knowledge into practice.

Little research has been conducted on science teachers' PCK of argumentation, and how their PCK of argumentation is reflected in the nature of classroom practices. An area of research suggests that teachers' PCK of argumentation may be mediated through their epistemological beliefs (Gess-Newsome, 2015). Science education literature discusses that science teachers' actions may reflect their knowledge of NOS, beliefs about science teaching and learning, students' ability, and nature of knowledge and knowing as their epistemological beliefs (Jones & Leagon, 2014). Teachers' classroom behaviors may also be related to contextual factors such as time concerns, resources, policies or standards (Marco-Bujosa et al., 2017; McNeill et al., 2016). Examining the influence of professional support on teachers' PCK of argumentation and epistemological beliefs and understanding whether their epistemological beliefs and other factors mediate the translation of teachers' PCK of argumentation and epistemological beliefs into instructional practices are the areas of the current study interested in to contribute to the development of science teachers.

Epistemological Beliefs and its Relation to Classroom Practice

Reform efforts have emphasized the epistemological underpinnings associated with the science education (Abell & Eichinger, 1998), that epistemology is labeled as the construct of nature of science. Sandoval (2005) argues that individuals' scientific epistemologies guide their learning and reasoning processes, which further influence understanding of the process of argumentation, the nature of knowledge and knowing, and their practices. As a critical party in the

learning process, science teachers may incorporate argumentation into instruction through reforming their epistemological beliefs or their epistemological beliefs change through developing PCK of argumentation and improving their practice accordingly.

Attempts to explore science teachers' beliefs about different constructs have been initiated in different contexts through various research designs. Studies have focused on investigating in-service science teachers' knowledge and beliefs about inquiry-based instruction through professional development programs (Herrington, Yeziarski, Luxford, & Luxford, 2011; Smith & Southerland, 2007; Wallace & Kang, 2004) and their beliefs about teaching and learning in general and their relation to the domain-specific beliefs (Belo, van Driel, van Veen, & Verloop, 2014). The research also focused on exploring the change in their knowledge of NOS after an intervention (Donnelly & Argyle, 2011; Mulvey & Bell, 2017; Posnanski, 2010), the translation of their NOS understandings into practice (Capps & Crawford, 2013; Herman, Clough, & Olson, 2013), and the influence of contextual factors on teachers' beliefs (Smith & Southerland, 2007; Wallace & Kang, 2004).

Research efforts (Braten & Ferguson, 2015; Chan & Elliot, 2004; Walker et al., 2012) also make a case for the change in teachers' epistemological beliefs as well as the direct or causal relationship between epistemological beliefs and conceptions about teaching and learning. Sinatra (2016) argues that epistemological beliefs are unlikely to change without targeted intervention. Researchers illustrate the shift in pre-service teachers' epistemologies through short-term or long-term interventions. For example, Walker and colleagues (2012) design a three-year intervention study through teacher education courses to track the change in pre-service domain-general epistemological beliefs. Brownlee et al. (2011) and Tanase and Wang (2010) examine the change in pre-service teachers' epistemological beliefs with a semester-long course. Researchers (Buehl &

Fives, 2009; Tanase & Wang, 2010) have also explored the consistency or inconsistency between pre-service and in-service teachers' epistemological beliefs on specific dimensions such as beliefs about the source and stability of knowledge and classroom practices.

A few studies address the debates on the relationship between pre-service teachers' domain-general and domain-specific epistemological beliefs (Liu & Liu, 2011; Schommer-Aikins & Duell, 2013). Not many studies have explored in-service teachers' domain-general epistemological beliefs. Moreover, an area of research focuses on science teachers' domain-specific epistemological beliefs and their relation to their practices, goals, and actions (Kang, 2008; Mansour, 2013; Wahbeh & Abd-El-Khalick, 2014). These studies argue that science teachers' beliefs about nature of knowledge and knowing may influence their domain-specific epistemological beliefs and classroom practices. Examining teachers' epistemology may contribute to understanding the ways, in which teachers' domain-general beliefs as well as domain-specific beliefs may be related to their PCK of argumentation and reflected or absent in their argumentation instruction.

A growing body of research indicates that epistemological beliefs have an impact on teaching and learning approaches and practices in different ways. There is empirical evidence about the consistency and inconsistency between science teachers' epistemological beliefs and instructional practices (Capps & Crawford, 2013; Herman et al., 2013; Mansour, 2013; Tsai, 2008) and how domain-general epistemological beliefs and domain-specific epistemological beliefs are related to each other and influence teaching and learning processes (Deniz, 2017). Even though Liu and Roehrig (2017) argue that teachers' epistemological beliefs define their willingness to teach and learn through argumentation, little is known about the interplay between science teachers' epistemological beliefs (both domain-general and domain-specific), PCK of

argumentation, and instructional practices. A research study is necessary to understand whether science teachers may develop high-quality PCK of argumentation and epistemological beliefs through attending professional development programs and translate their PCK of argumentation and epistemological beliefs into the instruction.

This study aims to explore the influence of a professional development program on science teachers' epistemological beliefs, PCK of argumentation, and argumentation instruction. The research has a qualitative case study design to explore the influence of one-year professional development program on urban science teachers' PCK of argumentation and epistemological beliefs (hereafter, both domain-general and domain-specific), whether teachers' PCK of argumentation and epistemological beliefs are reflected in their instructional practices. The study also aimed to explore what other factors mediate the argumentation instruction. The research questions guiding the present investigation are:

1. How does the participation in one-year professional development program influence PCK of argumentation and epistemological beliefs?
2. How are teachers' PCK of argumentation and epistemological beliefs reflected in their practice?
3. What other factors do teachers report as mediating the argumentation instruction?

Significance of Study

As an attempt to address a significant gap in the science education literature, the findings of this study have implications for the preparation of prospective science teachers as well as the development of in-service science teachers. Understanding the influence of a professional development program on argumentation instruction provides empirical evidence to inform the design of future professional development programs, teacher education courses or educative curriculum

materials to support teachers' PCK of argumentation and epistemological beliefs and to address other factors mediating argumentation instruction. Additionally, the study explores the science teachers' domain-general and domain-specific beliefs (epistemological beliefs) and how they are related to PCK of argumentation as well as classroom practice. Particular attention to the science teachers' epistemological beliefs may inform the teacher educators and science education researchers to understand how epistemological beliefs are related to the development of PCK of argumentation and argumentation instruction. The study generates interest in examining the interplay between urban science teachers' epistemological beliefs, PCK of argumentation, and instructional practices.

CHAPTER II

REVIEW OF THE LITERATURE

The Purpose

The primary purpose of this chapter is to provide a conceptual framework and theoretical background for the current study, which aims to explore the influence of one-year professional development (PD) program on urban science teachers' pedagogical content knowledge (PCK) of argumentation and epistemological beliefs. The study also aims to examine whether teachers' PCK of argumentation and epistemological beliefs are translated into the classroom practice and what mediating factors are useful in the argumentation instruction. A question of particular interest is whether the teachers, who participated in a one-year PD program and incorporated argumentation into science instruction during the academic year, can develop their epistemological beliefs and PCK of argumentation. A specific focus will be given to the relationship between these constructs- the linkage between epistemological beliefs, PCK of argumentation, and argumentation instruction. The mediating factors that may facilitate or hinder the translation of PCK of argumentation and epistemological beliefs will also be examined.

The Inclusion and Exclusion Criteria

The criteria for inclusion of the research studies in this review were: 1) the research report investigated teachers' domain-general epistemological beliefs, the changes in their beliefs after a professional development program or attending a methods course, and whether or not domain-general beliefs were translated into the instructional practices; 2) the research report examined science teachers' domain-specific epistemological beliefs (particularly beliefs about teaching and learning science and knowledge of NOS), the changes in their domain-specific

beliefs after a professional development program or attending a methods course, and whether or not domain-specific beliefs were translated into the instructional practices; 3) the research report aimed to explore the role of science teachers in incorporating the argumentation into classroom instruction and their challenges, strengths, as well as factors influencing argumentation instruction; 4) the research report utilized original or modified Toulmin's argumentation pattern as the structural elements of an argument for writing and classroom discourse; 5) the research report addressed science teachers' PCK of science topics, PCK of scientific inquiry as well as PCK of argumentation; and 6) the research articles published in a peer reviewed journal between 2000 and 2017 even though articles published after 2005 were given priority.

On the selection of research articles, the studies focusing on in-service teachers were the focus of the study, but due to limited research on in-service secondary or high-school teachers' epistemological beliefs, the studies on pre-service teachers and elementary and middle school grade teachers were also included. This review did not aim to evaluate teachers' beliefs about different constructs, but to provide a synthesized definition of epistemological beliefs; thus, studies addressing "teacher self-efficacy, motivation, or perception" were excluded from the review. Due to limited research on this area, studies between 2000 and 2005 were also included in this section of the review. For argumentation and pedagogical content knowledge constructs, the studies, whose participants were practicing (in-service) teachers (mainly secondary science teachers), were included, and selected articles were published after 2005. The studies on students' engagement in argumentation practices were not included in this review but utilized to address students' challenges in this practice.

The empirical studies were selected by the following procedure. First, the studies published between 2000 and 2017 were included in this review to present what has been involved in the literature in recent years. Second, two online databases, Web of Science and

ERIC (EBSCOhost), were searched with different keyword combinations for PCK of argumentation and epistemological beliefs. The articles addressing science teachers' knowledge of argument structure, knowledge of the dialogic process, and knowledge of student conceptions and instructional strategies were selected through following keywords interchangeably: "argumentation, science teach*, and professional development." "Knowledge, practice, instructional model (e.g., Science Writing Heuristics or Argument-Driven Inquiry), pedagogical content knowledge, and inquiry" words or phrases were also utilized to find the relevant articles. "Teacher beliefs" as a keyword was added to the search to find the studies addressing teachers' beliefs about argumentation instruction. The abstracts of studies from the databases were reviewed to identify the relevant studies or peer-reviewed journal articles. A total of 25 studies were selected for the review as appropriate for the research focusing on argumentation, argumentation instruction, professional development, pedagogical content knowledge, and teacher beliefs.

Furthermore, for domain-general epistemological beliefs, the literature was searched with the following keywords interchangeably: "epistem* beliefs, epistemological beliefs, personal epistemology, teacher, teach*, beliefs about knowledge, beliefs about learning or knowing, beliefs about teaching and learning, knowledge, and practice." A total of 11 studies was selected for review on domain-general epistemological beliefs; the selected articles were mostly from *Teaching and Teacher Education*, *Contemporary Educational Psychology* highly cited journals. For science teachers' epistemological beliefs on both domain-general and domain-specific epistemological beliefs, the literature was searched with following keywords interchangeably: "epistem* beliefs, epistemological beliefs, science teacher, science, beliefs about knowledge, beliefs about knowing, beliefs about teaching and learning science, inquiry/reform instruction,

professional development, teacher beliefs, and instructional practice.” A total of 13 studies was selected for review on science teachers’ epistemological beliefs and their beliefs about science teaching and learning, particularly, beliefs about inquiry-based instruction. Lastly, the literature search focused on finding published literature about science teachers’ knowledge of NOS through using keywords interchangeably: “nature of science, inquiry, knowledge, practice, professional development, and teach*.” A total of 11 articles were found relevant for review. The selected journals on scientific argumentation, PCK of argumentation, and science teachers’ epistemological beliefs were from highly cited journals in science education including *Journal of Research in Science Teaching*, *Science Education*, *International Journal of Science Education*, and *Journal of Science Teacher Education*.

The Review of the Literature

This critical review focused on science teachers’ epistemological beliefs, PCK of argumentation, and implementation of argumentation. The review of the published literature was divided into four sections based on the focus of selected articles: 1) Scientific argumentation and teacher roles for argumentation instruction: This section examined the importance of scientific argumentation in science education and the role of teachers’ in promoting argumentation instruction addressing pedagogical practices, instructional models, teacher challenges, and beliefs. 2) PCK of argumentation: This section defined the term PCK and examined studies focusing on topic-specific PCK for scientific inquiry and argumentation. 3) Epistemological beliefs: This section examined studies focusing on pre-service and in-service teachers’ domain-general and domain-specific epistemological beliefs. Studies from peer-reviewed journals were selected considering the purpose of the study addressing the changes in teachers’ epistemological beliefs, the relationship of epistemological beliefs with teachers’ conceptions about teaching and

learning as well as instructional practices. A particular focus was given to science teachers' scientific epistemological beliefs. The conclusion part of this chapter provided a synthesis of the review, further implementations on each area of study, and the gaps in the literature concerning teachers' epistemological beliefs, PCK of argumentation, and argumentation instruction.

Science Education and Argumentation

Recent national (e.g. AAAS, 1993; NRC, 2007, 2012) and international reform documents (e.g. ACARA, 2009; DCSF, 2009) and research (e.g. McNeill et al., 2017; Osborne et al., 2013; Sampson et al., 2011) directed the central focus on teaching and learning science through argumentation to develop learners' knowledge, practices, and skills about cognitive, epistemic, and social aspects of science (Cavagnetto, 2010; Duschl, 2008; McDonald, 2016). Historically, science was defined as a body of knowledge constructed through a universal method of formulating and verifying hypothesis in an orderly process (Windschitl, Thompson, & Braaten, 2008). As such, learners were not able to engage in the epistemology of science to promote their cognitive and metacognitive processes, critical reasoning, and communication skills through writing, reading, and talking as well as to understand the cultural aspects of science (Cavagnetto, 2010; Jimenez-Aleixandre & Erduran, 2008; Kuhn, 2005). This approach was parallel to teacher-centered instruction that resulted in a focus on transferring the facts, the lack of student autonomy, and less engagement in scientific practices and meaningful learning.

Many scholars criticized the approach referring to scientific knowledge as certain and objective (Dewey, 1910; Hofer & Pintrich, 1997; Schwab, 1962). Dewey (1916) thought that science teaching focused on the memorization and failed to promote application of concepts in real-life situations. In 1960s, Schwab (1962) approached science teaching as an "enquiry to enquiry" (p. 65) rather than "rhetoric of conclusions" (p. 24), which emphasized students' active

involvement in their own learning process to enculturate learners in the process of science including diversity of methods such as generating, evaluating, and communicating scientific explanations based on evidence (Jimenez-Aleixandre & Crujeiras, 2017; NRC, 2012). Rudolph and Horibe (2016) argued that besides understanding the science content, learners should understand the social and epistemic aspects of science; in other words, what students learned about science in schools should help them learn the language processes as well as consider the moral, political, and ethical issues in the society (Erduran, 2015).

The recent United States (US) *K-12 Framework for Science Education* (NRC, 2012) suggested that learners should be involved in a set of scientific practices experienced by the community of scientists to develop higher order competencies including investigation, evaluation, and scientific explanations rather than the performance skills necessary to replicate the procedural steps (Osborne, 2014). This vision led to the development of a subsequent document, *Next Generation Science Standards* (NGSS Lead States, 2013), which addressed the “synergy between the disciplinary core ideas, the crosscutting concepts, and the practices inherent to the complexities of learning science” (Cheuk, 2016, p. 93). This interaction provided a context for science teaching and learning to develop scientific knowledge as well as understand the scientific practices and the common concepts that had universal meaning for various disciplines such as patterns, cause and effect, and systems and system models (NGSS Lead States, 2013).

The science standards addressed the core scientific practice- *Engaging in argument from evidence* to provide a context for students to develop science content knowledge through engaging in social and material aspects of science- as a process of construction, critique, and refinement of knowledge claims through diversity of methods and reflective participation as the practices of scientific community (Berland et al., 2016; Ford, 2008; NRC, 2012; Osborne, 2014). This practice

had been supported as a significant component of scientific literacy to support learners' development of conceptual understanding (Bell & Linn, 2000; Zohar & Nemet, 2002) as well as writing and talking in the language of science (Cavagnetto, 2010; Norris & Phillips, 2003). Furthermore, scientific argumentation promoted students' understanding of the epistemic goals of science- "how and why the natural world works in the ways it does" (Berland et al., 2016, p. 1085) in the process of generating evidence-based explanations through designing investigations, collecting and analyzing data, and justifying the knowledge claims as well as acknowledging the multiple ideas in a collaborative group activity (Osborne et al., 2004).

Education researchers (e.g., Jimenez-Aleixandre & Erduran, 2008; Kuhn, 1991; O'Keefe, 2002; Van Eemeren, Jackson, & Jacobs, 2015) have defined the word "argument" in two senses. First, an argument is a product that an individual constructed an argument through supporting a claim with relevant evidence and justification. Second, the argument is a process that referred to the social processes that two or more individuals engage in dialogue to construct and critique arguments. In science education literature, scientific argumentation has been emphasized with having both the structural and dialogic focus to articulate, justify, and communicate claims, explanations, and viewpoints (Jimenez-Aleixandre & Erduran, 2008; Sampson & Clark; 2008; McNeill et al., 2006).

The significant body of literature utilized the original or modified Toulmin's Argumentation Pattern (TAP) (Sampson & Clark, 2008) including structural elements of an argument as "claim, data, warrant, backing, rebuttal, and qualifier" to construct claims and justify them by evidence (Toulmin, 1958). For instance, McNeill and colleagues (2006) modified the TAP as an instructional framework including three elements: claim (a conclusion about a problem), evidence (data that supports the claim), and reasoning (a justification, built from scientific principles, for why the evidence supports the claim). In a recent study, Sampson and colleagues (2011, 2013) described the

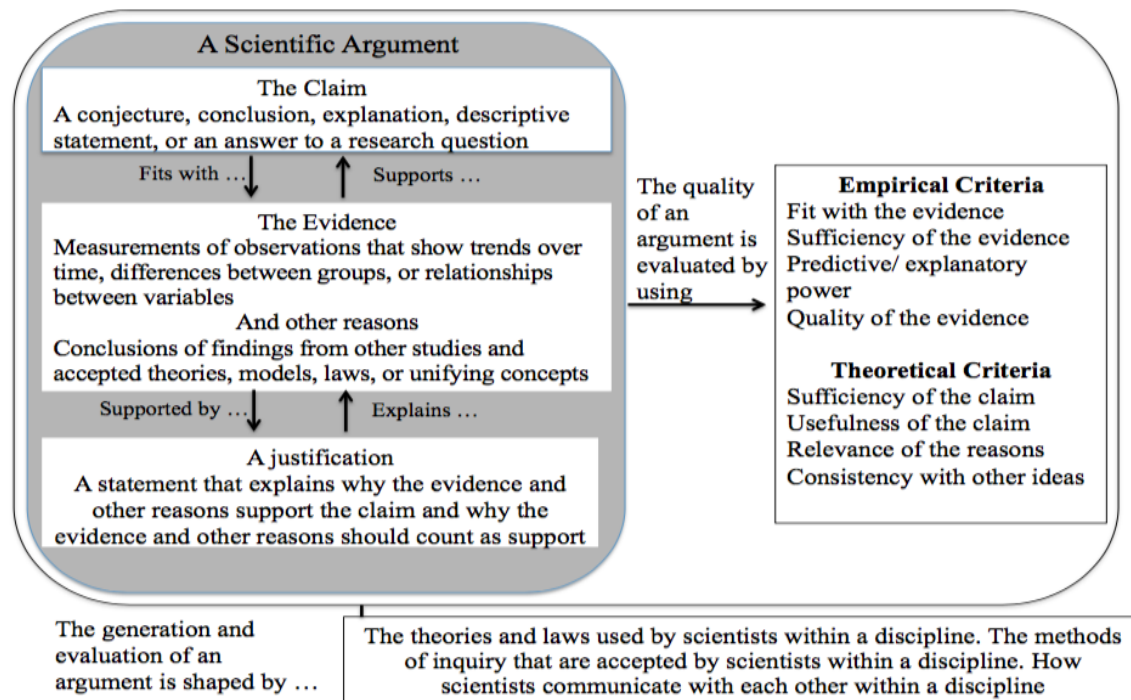
structure of a scientific argument as a claim supported by evidence and justification of the evidence. The data were collected through experiments and observations and interpreted as evidence to represent the validity and acceptability of a claim in the form of graphs, tables, diagrams, photographs, or text to demonstrate the change in time and the comparison and relationship across the groups (Walker & Sampson, 2013; Cheuk, 2016). The justification was defined as the explanation of the relevance of evidence and why the evidence supports the claim (Sampson et al., 2013). Figure 1 represented the model that this study utilized to describe the components of an argument structure in science.

Argumentation also involved a dialogic process as the social aspect of argumentation, in which individuals constructed knowledge through interacting with others to learn a task together—listening to alternative ideas, engaging in critique, and building on each other’s ideas (Alexander, 2005; Jimenez-Aleixandre & Erduran, 2008). Similarly, Ford (2008a, b, 2012) made the case for scientific sense-making through engaging in a “grasp of practice,” in which learners attained the roles of both constructor and critique to construct scientific claims and show appropriate reasons for how, under what circumstances, and why a scientific claim needed to be critiqued. Ford addressed the work of scientists as socially negotiated that they conducted an experiment or investigation to make evidence-based explanations about a scientific problem and discuss the alternative ideas with other scientists to enhance the objectivity, make revisions, and reach a consensus about the scientific claims. He argued that learners’ engagement in this practice enculturated them into social and material aspects of science to construct knowledge of content and develop critical reasoning and literacy skills including scientific writing and accountable talk. Science teachers needed to develop the knowledge of student conceptions and appropriate

pedagogical strategies to promote student-centered instruction and support students' engagement in scientific argumentation.

Figure 1

A framework to illustrate the component of a scientific argument and criteria to evaluate the argument (Sampson, Enderle, & Grooms, 2013)



Science Teachers' Role in Argumentation Instruction

A national survey among science teachers in grades K-12 (Banilower et al., 2013) indicated that science teachers fairly emphasized reform-centered instruction to develop an understanding of science concepts through enhancing student participation and interest with small group discussions and hands-on activities and making connections to real-life situations. Instead, teachers in the study stated that they preferred teacher-centered instruction to explain the concepts and solve textbook problems. Traditional approach to teaching presented science as discrete facts and science learning as an individual activity to cover the standards (NRC, 2012;

Roth & Garnier, 2007); a teacher was at the center of the interactional pattern in the form of Triadic or Initiate-Response-Elaborate pattern (González-Howard & McNeill, 2017; Mortimer & Scott, 2003). Alternatively, McNeill and Berland (2017) suggested framing the science instruction as phenomena-based and transformable focusing on collection and interpretation of empirical data about a natural phenomenon and identifying and evaluating the patterns to construct evidence-based explanations within a collaborative process. Dialogic interactions also helped students co-construct knowledge through making, justifying, and refuting claims in a collective sense-making process.

Linking to the previous arguments (Berland & Reiser, 2009; Berland & McNeill, 2010), science teachers had an essential role in establishing classroom norms, in which students engaged in multiple practices including the use of both structural and dialogic aspects of argumentation. In other words, teachers need to establish a classroom culture, in which students could develop knowledge collectively through constructing and defending alternative ideas and reaching a consensus rather than transferring the information from the authority (i.e., teacher or textbook) or focusing on the right answers.

In recent years, new instructional models have been developed as alternative approaches to traditional instruction and cook-book type laboratory activities to incorporate cognitive, social, and epistemic aspects of science into science teaching. These instructional models embedded into the scientific practices such as designing and carrying out scientific investigations, crafting evidence, and justifying them with scientific principles as well as exchanging alternative viewpoints in groups or whole class discussions to reflect the nature of scientific knowledge (Duschl, 2008; Jimenez-Aleixandre & Crujeiras, 2017; Sampson et al., 2013). However, innovating approaches focusing on argumentation required more than the adaptation of these

new curriculum materials, but a change in teachers' role from an authority to a facilitator (Zohar, 2008). These instructional models aimed to provide supportive framing for the science instruction to create a classroom culture around the practices of scientists including hands-on activities and use of language of science and semiotic resources such as oral and written language, mathematics, tables, graphs, and diagrams (Berland & McNeill, 2010; Cavagnetto, 2010; McNeill & Knight, 2013; Sampson et al., 2011).

For example, Argument-Driven Inquiry (ADI) instructional model has been designed as a template for developing a laboratory-based activity, addressing science and engineering practices, crosscutting concepts, disciplinary core ideas, and nature of science (Sampson et al., 2011; Sampson et al., 2013). The model supported the student-centered instruction to take the ownership of their own learning through being involved in the design of an investigation, data collection and analysis, development of an argument, exchanging ideas and discussing findings with peers, and the writing and revising the investigation reports based on the feedback offered by the reviewers (Walker et al., 2012). The model also aimed that students' participation in ADI investigations - generation and validation of scientific knowledge helped them develop conceptual understanding, scientific reasoning, and scientific habits of mind.

Sampson et al. (2011) utilized the ADI model to examine how various laboratory activities influenced students' argumentative writing skills along with the understanding of core scientific ideas. They collected data from nineteen 10th grade students enrolled in a chemistry course through performance tasks as pre- and post-intervention and video-recordings of group discussions. Participants worked on ADI activities and required to write investigation reports through developing, reflecting on, elaborating, and revising explanations based on scientific concepts, laws, and theories. The results indicated that ADI model provided a great promise and potential to improve students'

engagement in many aspects of argumentation. For example, they could develop a better understanding of what counts as an explanation, evidence, and reasoning, and students were more likely to discuss and challenge each other's ideas with greater frequency after the intervention. However, the findings showed that students mostly relied on their prior knowledge or everyday language to understand the natural phenomena. This result indicated that instructional model was not successful in encouraging students to use scientific theories or laws to make sense of their observations or to critique the validity of acceptability of a potential explanation.

A follow-up study by Sampson and colleagues (2013) explored whether students' engagement in various tasks embedded into ADI model could improve their argumentative writing skills along with conceptual understanding across two semesters. Participants were 294 students of six teachers teaching life science, physical science, biology, or chemistry course in a K-12 university laboratory school. Each student participated in at least eight ADI investigations in one semester and completed argumentative writing and science content assessments, which were assessed through rubrics. The results indicated that students could improve science-specific argumentative writing skills and learn important content at the same time through a writing-to-learn approach of ADI activities. There was a positive relationship between the number of investigation reports that students wrote in a semester and the improvement in their science-specific argumentative writing skills. The science content assessment scores reported students' learning gains, which were reflected in the discussion of core scientific ideas through writing. The authors argued that each teacher's interpretation and implementation of ADI activities were unique that influenced students' learning differently through ADI investigations. The study suggested that further research should focus on teachers' enactment of the ADI model- how teachers adapted or modified the model to promote meaningful learning for diverse students.

Furthermore, Keys (1999) designed Science Writing Heuristic (SWH) as a tool for both teachers and students to integrate scientific argumentation into science laboratory activities to promote conceptual understanding through writing, metacognitive thinking, and learners' ownership and responsibility within the process of science learning (Wallace, Hand, & Yang, 2004). During the laboratory activities, students generate questions related to a scientific investigation, construct claims based on interpretation of data, compare their results with other groups, and reflect on the changes in their ideas (Choi et al., 2015). In Martin and Hand (2009)'s study, the authors made a case for the critical role of the teacher in promoting argumentation and investigated an experienced fifth-grade elementary science teacher's implementation of SWH approach through working with a professional development liaison. Transcriptions of classroom discourse were analyzed using the Toulmin's (1958) model to define the time devoted to teacher voice and student voice as an argument. The researcher also conducted interviews with the professional development liaison about the change in the instructional practices of the teacher. The results of the study demonstrated that there was a remarkable change in the teacher's practices from teacher-centered approach to student-centered approach. As the teacher's questioning pattern changed, student voice as well as the complexity of arguments increased. As students became more familiar with the claim, evidence, and rebuttal components, they were more involved in the peer-to-peer discussion to evaluate other's claims, and the teacher became the listener and resource person. The findings provided empirical evidence for the effectiveness of explicit argumentation instruction with the SWH approach to promote the dialogic interaction in the science classroom.

In a similar study, Choi and colleagues (2015) investigated the successes of 19 teachers in the enactment of SWH approach after attending a two-week professional development program on argument-based inquiry. The analysis of teachers' written reflections on teaching

experiences indicated that teachers approached SWH as a template for students to organize, clarify, articulate, and communicate their thoughts with the writing-to-learn approach. Teachers thought SWH approach was an opportunity to integrate authentic learning and discourse as well as to enhance students' conceptual understanding. During the enactment, teachers utilized various strategies such as generating testable questions, designing procedures, and writing reflections, modeling ways of how to construct claims and evidence, and modeling class discussions to build a sense of what was a reasonable argument. The instructional model helped teachers engage students in the use of argumentation in different ways.

Furthermore, McNeill and colleagues developed an instructional framework to support teachers' lesson planning and instructional decisions around scientific explanations. McNeill and Krajcik (2008) explored the role of a teacher in structuring and guiding middle school students to construct scientific explanations about phenomena around claim, evidence, and reasoning framework. Thirteen teachers were introduced to the "Investigating and Questioning our World through Science and Technology (IQWST)" curriculum materials embedded into an instructional model addressing four practices for argumentation: defining and modeling scientific explanation, making the rationale of scientific explanation explicit, and connecting scientific explanation to everyday practice. Teachers in this study mostly incorporated the "defining and modeling scientific explanations" practice in different qualities, but they rarely provided the rationale behind a scientific explanation. The authors argued that defining and modeling practices addressed procedural or algorithmic aspect rather than emphasizing the social aspect of argumentation. However, a teacher, who made the explicit rationale of a scientific explanation, helped students understand why they needed to include evidence and reasoning to support their claims. Their students had more significant learning gains and a stronger understanding of scientific explanations

than a teacher, who did not make the rationale. Teachers' connection the scientific explanations to everyday practice could give students opportunity to examine more cases from different perspectives. The authors concluded that small sample size was the limitation of the study. Teachers' enactment of the instructional model should be explored in longitudinal studies to track the changes in teachers' practices over time and how these practices influenced student learning.

Developing these instructional models supported teachers to build knowledge of instructional strategies to teach through scientific argumentation. They aimed to integrate both structural elements and dialogic aspect of argumentation into science instruction to promote students' conceptual understanding and to communicate their ideas with their peers through written and oral explanations. However, the empirical studies pointed out that teachers experienced challenges in enacting these models with fidelity. For example, science teachers struggled with both the structural and dialogic characteristics of argumentation (e.g., McNeill et al., 2016; Simon, Erduran, & Osborne, 2006; Sampson & Blanchard, 2012). In terms of structural elements of an argument, teachers had difficulty in providing appropriate evidence to support claims (Sampson & Blanchard, 2012) and in using or evaluating students' reasoning in their writing and talking (Crippen, 2012; McNeill & Knight, 2013) as well as in evaluating the quality of arguments (Knight-Bardsley & McNeill, 2016). If teachers had little or no experience with argumentation or lack understanding of what does and does not count as an argument, they could focus more on the structural aspect as a technical tool without having a more profound knowledge of this scientific practice (Simon et al., 2006; McNeill, 2009).

In Sampson and Blanchard (2012)'s study, the authors examined science teachers' challenges in teaching scientific argumentation through collecting data from 30 teachers with Cognitive Appraisal Interview (CAI) and course artifacts. The results indicated that teachers struggled in

designing argument-based lessons due to their lack of confidence, knowledge, and resources to promote students' engagement in this scientific practice. Teachers had difficulty in constructing arguments including evidence to support a claim and justification of evidence. They relied on their personal understanding of the phenomenon, content knowledge, and past experiences to provide an explanation and evaluate its validity or acceptability. In another study, Crippen (2012) aimed to describe how 42 high school science teachers engaged in argumentation through participating a two-week argue-to-learn professional development experience related to climate change. The study collected data through science content test, recordings of group presentations, artifacts, and a semi-structured focus group interview. Teachers in this study experienced significant change in content knowledge on global climate change after the intervention. They were comfortable in defining the concept and identifying examples as well as in citing the evidence from the resources in different forms such as charts or tables; however, they had challenges with constructing their own models and understanding and using the reasoning explicitly during the instruction.

Teachers need to develop an understanding of scientific argumentation as a significant aspect of teacher knowledge and science instruction (Evagorou & Dillon, 2011). Science education researchers designed professional development programs, workshop meetings, educative curriculum materials or science method courses to address teachers' challenges in integrating argumentation. These interventions aimed to provide teacher learning opportunities to enhance teacher knowledge, practice, and their students' learning. Desimone (2009) argued that professional development should focus on the content and pedagogy coherent with state reforms and policies and provide opportunities for engaging in active learning such as observing expert teachers, collaborating with other teachers, participating in discussions, and providing feedback to each other. Osborne and colleagues (2013) suggested that teacher learning could be achieved "with more sustained and intensive professional

development that requires more resource of teacher time, peer support, or coaching and models of what are the major identifiable steps in pedagogic practice with argumentation in school science” (p. 341). Although the literature has not indicated a specific period for professional development to achieve teacher change, Roth and colleagues (2011) suggested a minimum 100 hours of professional development, and Osborne and colleagues (2013) thought minimum two-year experience with argumentation instruction as necessary to achieve changes in teachers’ instructional practices and promote student learning. In particular, for argumentation, as Sampson and Blanchard (2012) highlighted, in-service and pre-service teachers should be supported to learn about the nature of scientific argumentation and enhance knowledge and skills to develop new curriculum materials and resources and to incorporate argumentation into science instruction.

An area of research on teacher learning focused on teaching structural elements of an argument through science methods courses. Sadler (2006) documented how argumentation was incorporated into science instruction by 17 pre-service middle and secondary science teachers attending a secondary methods course. The lesson artifacts and participants’ reflections on their field experience focusing on argumentation and discourse were utilized as data sources of the study. The results indicated that most participants considered argumentation as having a central role in planning the science instruction to enhance student learning, and they were willing to design instruction around argumentation to promote student discourse. Highlighting the basic elements of argumentation and pedagogical strategies to construct high-quality arguments including counterarguments and rebuttals, engaging students in critique demonstrated the positive impact of science methods course on pre-service teachers’ teaching and learning argumentation.

Teachers also developed new resources and activities to promote argumentation in science lessons. In Simon and colleagues’ (2006) work, five science teachers were introduced to

instructional strategies during the professional development program to teach a zoo lesson. The analysis of their enactment indicated that teachers constructed simple arguments including claim-data combinations during the first year of the implementation. However, the nature of their use of argumentation became more complex in the second year of the study, and they made justifications to their claims through providing warrants and backings. In terms of classroom discourse, participants valued the argumentation and integrated small group discussions, whole class debate and reflection, and role play to promote the use of evidence and justification. In doing so, teachers encouraged students to define the argument, discuss, listen, evaluate the context and process of arguments, and reflect on their experiences. They also used writing frames to guide students' construction of arguments and played devil's advocate in small group and whole class discussion as a way to extend students' arguments.

Studies also aimed to explore whether teachers' use of argument structure differed depending on the mode of inquiry. Gray and Kang (2014) examined whether and how four secondary science teachers constructed scientific arguments while teaching different units relying on experimental and historical modes of inquiry. Participants were the expert teachers of the district, and the data were collected through classroom observations and interviews. Throughout the study, the quality of teachers' arguments was not different. Teachers, who taught the units focusing on either the experimental or historical modes of inquiry developed simple arguments including a claim supported by evidence, but lacking qualifiers and rebuttals. However, more evidence was used during the historical topic units rather than experimental topic units. The findings of the study suggested that the nature of the topic and mode of inquiry influenced the amount of evidence rather than the quality of the arguments. These results were aligned with a previous argument from Osborne et al. (2004) that supporting and developing argumentation in a scientific context was significantly harder than integrating argumentation in a

socio-scientific context. Specifically, the argument in a scientific context required specific knowledge of the phenomenon to evaluate the scientific evidence, but for socio-scientific issues, people could quickly draw on ideas and expertise developed through experiences.

According to Cheuk (2016), science teachers took advantage of the language practice of argumentation to create learning opportunities and address language and literacy demands of science standards. Swanson and colleagues (2014) investigated the ways of how an urban high school science teacher supported English Language Learners (ELLs) in scientific argumentation. The teacher focused on teaching the academic language through different activities including investigations and interpretation of cartoon images via the whole class discussions and small group activities. The teacher provided primary language supports through scaffolding and rephrasing students' contributions to help them understand the difference between data and claim, how and why claims are supported by evidence, and emphasize the structural elements of arguments explicitly. The study recommended that future research should examine how teachers could promote accountable talk and model academic language to engage diverse students in constructing and communicating arguments.

Solely addressing the structural aspect of argumentation might lead teachers to focus on the surface-level features of the practice. Science teachers also needed to incorporate the dialogic dimension of argumentation- both construction and critique of multiple claims as well as building on each other's ideas through collaborative learning tasks (Ford, 2008; Osborne et al., 2013). Little research focused on teachers' challenges in this aspect. For example, Alozie, Moje, and Krajcik (2010) reported that high school teachers had difficulties in promoting dialogic discourse due to their concerns about covering the content, teaching abstract concepts, and connecting to everyday discussions. Gonzalez-Howard and colleagues (2017) found that teachers thought promoting competing claims might result in the development of incorrect ideas about science content.

Christodoulou and Osborne (2014) conducted a case study of a secondary science teacher to explore how the teacher promoted epistemic discourse after two-year professional development on argumentation instruction. The analysis of classroom observations, informal discussions, and samples of student work indicated that teacher had the role of “constructor,” and the evaluative practices were not embedded in the construction of knowledge claims. The teacher promoted the epistemic discourse through constructing and justifying the knowledge claims to develop science concepts and support students’ scientific thinking rather than engaging students in the process of revising and evaluating ideas. The study suggested the design of future studies or training programs to develop tools and resources as well as to improve teachers’ epistemic discourse practices, in particular, to evaluate and revise ideas.

Teachers’ framing of discussions in science classrooms influences how they encourage students to engage in dialogic argumentation. If the goal of the lesson were to explore and probe students’ ideas, a more dialogic and interactive discourse pattern would be effective in the classroom. McNeill and Pimentel (2010) and Pimentel and McNeill (2013) examined the patterns of classroom discourse to understand how high school science teachers supported both the structural and dialogic aspects of scientific argumentation while teaching standards-based urban ecology curriculum. The authors utilized video-recordings of lessons focusing on whole class talk. McNeill and Pimentel (2010) indicated that there was a relationship between teachers’ use of open-ended questions and promoting argumentative discourse. Students could support their claims with appropriate evidence and build knowledge through engaging in refutation or clarification of ideas through collaboration. However, the teacher-dominant class included less open-ended questions and little discourse, and students were less active and did not engage in justification of evidence. In Pimentel and McNeill (2013)’s study, all teachers focused on transmitting facts about developing a researchable question and listing evidence rather than students’ active participation. They had

difficulties in promoting science talk and meaningful science learning as they prioritized content coverage. These studies suggested that teachers needed to understand the classroom culture as complex including cognitive, social, and epistemological norms to enhance student learning through argumentation. Teachers' lack of knowledge about argumentation might influence how they promoted classroom discussions and student learning.

Considering the significance of teacher knowledge, Avraamidou and Zembal-Saul (2005) examined a first-year elementary teacher's development of knowledge and practices in prioritizing the evidence-based explanations in science instruction through science methods courses. Data were collected through classroom observations, semi-structured interviews, and lesson artifacts such as lesson plans, assessment tasks, and student homework. The participant's instructional practices included an emphasis on the role of evidence-based explanations through experimentation and observation during the whole-class discussions and small-group work. The teacher also engaged the students in data collection, analysis, and interpretation to construct and communicate explanations through talking and writing.

In a similar study, Zembal-Saul (2009) examined 17 pre-service teachers' abilities to integrate argumentation into classroom instruction. The participants joined an experimental professional development program to experience teaching science as an argument. Student teachers articulated and analyzed their personal histories as science learners and prepared activities to elicit their students' ideas about a particular phenomenon. The results indicated that supporting preservice teachers in argumentation instruction provided a continuum for science teaching, which changed the implementation from activity-based to investigation-based, then to evidence-based, and then to argument-based instruction. At the beginning of the study, teachers focused on hands-on activities as fun and exciting for students. By the end of the course, they described investigations as means for collecting data to make evidence-based explanations; teachers elicited

and became aware of student ideas to support the construction of scientific arguments. Teachers could enact more argument-based instruction through focusing on the structure of argument and role of language as a guide for classroom discussions and making students' thinking visible through reasoning about the development and evaluation of claims from evidence.

Studies from Zembal-Saul and colleagues highlighted the significance of supporting pre-service and in-service teachers in developing knowledge and pedagogical practices to enhance student learning. These authors emphasized the role of the teacher in the understanding of the function of evidence-based explanations to guide students' thinking and construction of arguments during the classroom discussions. They suggested that further research should explore the ways to develop teachers' pedagogical content knowledge (PCK) of scientific argumentation, specifically, evidence-based explanations through larger-scale and longitudinal studies. The following section focuses on the role of PCK of argumentation as a topic-specific dimension through building on the discussions related to PCK of science topics and PCK of scientific inquiry.

Pedagogical Content Knowledge

PCK is defined as a component of teacher professional knowledge used in lesson planning, topic-specific instruction in a particular classroom context, and skill involved in the act of teaching (Gess-Newsome, 2015). Shulman (1987) argued that teaching was complicated, and teacher knowledge required more than competence in subject matter and classroom practice; effective teaching began with an understanding of what students needed to learn and how a topic should be taught. Shulman (1986) suggested three domains about content knowledge in teaching, including subject matter knowledge (SMK), pedagogical content knowledge (PCK), and curricular knowledge (CK). Shulman (1987) elaborated on this model suggesting seven knowledge-based domains: content, pedagogy, curriculum, learners and learning, contexts of schooling, educational

philosophies, goals, and objectives, and pedagogical content knowledge. PCK is defined as the intersection between pedagogy and content as a required knowledge for teachers to teach the content and skills of the curriculum to students of different ages and backgrounds (Shulman, 2015).

Abell (2008) pointed out that Shulman's conceptualization provided a theoretical framework to understand how teachers' pedagogical practices developed and how content knowledge was represented to establish the knowledge of effective pedagogy for science teaching. Shulman's ideas have been modified to develop alternative PCK models. Table 1 represented the different conceptualizations of PCK modified from Lee and Luft (2008). For example, Grossman (1990) considered that four general areas were essential for English teachers' knowledge base: "general pedagogical knowledge, subject matter knowledge, pedagogical content knowledge, and knowledge of context" (p. 5). In Grossman's conceptualization, PCK included four central components: knowledge and beliefs about purposes of teaching a concept at different grade levels, knowledge of students' understanding and difficulties, knowledge of curriculum, and knowledge of instructional strategies.

Grossman (1990)'s PCK model informed the development of Magnusson, Krajcik, and Borko (1999)'s model in science education, which was defined as "a transformation of knowledge from other domains" (Magnusson et al., 1999, p. 96). According to the Magnusson and colleagues, PCK involved five dimensions: orientations toward science teaching, knowledge and beliefs about science curriculum, knowledge and beliefs about students' understanding of specific science topics, knowledge and beliefs about assessment in science, and knowledge and beliefs about instructional strategies for teaching science. The Magnusson et al. (1999) model was similar to Shulman (1986) and Grossman (1990)'s conceptualization called "transformative model of PCK" as the synthesis or combination of the separate elements for instruction that subject matter knowledge, pedagogy, and context. This transformative approach was different from the

“integrative model of PCK” proposed by Gess-Newsome (1999) as the integration of knowledge of subject matter, pedagogy, and context as a whole.

This study will focus on two components of knowledge dimensions (knowledge of students and knowledge of instructional strategies) that are the common elements in Shulman (1986)’s original conceptualization and included in Grossman’s and Magnusson et al. conceptualizations as demonstrated in Table 1. The recent studies also highlighted that these areas (knowledge of students and knowledge of instructional strategies) required more significant support for the professional development of teachers (Kind, 2009; McNeill & Knight, 2013; McNeill et al., 2016).

Knowledge of student conceptions dimension addresses teachers’ knowledge of students’ prior knowledge, learning abilities and approaches, alternative conceptions, and students’ challenges in learning science topics (Grossman, 1990; Magnusson et al., 1999). This component refers to the necessary knowledge that teachers need to have to plan instruction based on students’ strengths and weaknesses and to identify the challenges.

Besides, teachers need to develop a repertoire of appropriate instructional strategies to accommodate students’ weaknesses in learning a topic. Magnusson and colleagues (1999) categorized knowledge of instructional strategies as knowledge of subject-specific and topic-specific strategies, in which the former referred general approaches to teaching science consistent with the learning objectives, and the latter addressed the ways that the teacher represented concepts and principles such as models, demonstrations, or analogies related to the science topic. Teachers’ knowledge of students’ conceptions influenced the selection of appropriate instructional strategies as well as their application (Kind, 2015); therefore, these instructional strategies should be appropriately selected to make a specific content knowledge accessible to students.

Table 1

Different conceptualizations of PCK modified from Lee and Luft (2008)¹

Reference	Knowledge of							
	Subject matter	Instructional strategies	Student conceptions	General pedagogy	Curriculum and media	Context	Purpose	Assessment
Shulman (1987)	a	PCK	PCK	a	a	a	a	b
Tamir (1988)	a	PCK	PCK	a	PCK	b	b	PCK
Grossman (1990)	a	PCK	PCK	a	PCK	a	PCK	b
Marks (1990)	PCK	PCK	PCK	b	PCK	b	b	b
Magnusson et al. (1999)	a	PCK	PCK	a	PCK	a	PCK	PCK
Carlsen (1999)	a	PCK	PCK	a	PCK	a	PCK	b
Loughran et al. (2001)	b	PCK	PCK	b	PCK	b	PCK	PCK

¹ “a” represents distinct category in the knowledge base for teaching; “b” represents that the knowledge domain was not discussed explicitly; PCK represents the pedagogical content knowledge.

Teachers need to develop PCK for science topics addressing students' strengths and challenges about science, science curriculum materials, and strategies to promote science learning. They must develop PCK for scientific inquiry to promote science learning through inquiry including asking and answering questions, designing and conducting investigations, collecting and analyzing data, and develop explanations based on evidence (Beyer, Delgado, Davis, & Krajcik, 2009; Davis & Krajcik, 2005; NRC, 2012). Moreover, the research on PCK focused on teachers' knowledge of teaching particular topics (Van Driel, Verloop, & de Vos, 1998; Loughran, Berry, Mulhall, & Woolnough, 2006) and knowledge of inquiry-based instruction (Lee, Brown, Luft, & Roehrig, 2007; Park & Oliver, 2008), there is also a need to address teachers' knowledge of scientific practices in parallel to the need for teachers to promote students' engagement in common practices of science (Berland et al., 2016; Osborne, 2014). Addressing the development of teacher expertise on various knowledge domains is essential to enhance student learning around student-centered instruction as suggested by national and international documents (e.g., ACARA, 2010; NRC, 2012). The following two sections will focus on PCK of scientific inquiry PCK of argumentation.

PCK of scientific inquiry. Teachers' instructional decisions are influenced by teachers' PCK to plan the instruction and develop students' understanding of science. The development of PCK is a dynamic process and requires professional experience to be refined and improved. Beginning and pre-service science teachers may have limited PCK as an experiential knowledge developed through classroom experience over time, and strong science background does not guarantee a proficient level of PCK (Lee et al., 2007). PCK is developed through the interaction of different elements of knowledge domains such as the combination of knowledge of students' conceptions, resources, and content knowledge, teaching experience, professional development

opportunities, and guided reflection. Their implementation of reformed science teaching approaches may be correlated to their sophisticated PCK (Park, Jang, Chen, & Jung, 2011).

Lee and Luft (2008) explored the concept of PCK with four experienced secondary science teachers through interviews, classroom observations, and reflective journals. Teachers had the combinations of various knowledge dimensions for PCK. They possessed knowledge of science teaching addressing science content, scientific practice, the nature of science, and scientific processes. They also held knowledge of students referring to their learning needs, interests, prior knowledge, difficulties, and alternative conceptions to determine the instructional goals such as scientific literacy, real-life application, and conceptual understanding. Teachers utilized various teaching methods and activities linked to their knowledge of resources and assessment to accommodate and evaluate students' learning to determine what and how to teach.

Teachers' reflection on their instructional practices may influence the development of PCK for student conceptions. Teachers' reflection-in-action and reflection-on-action can help them be aware of the strengths and challenges of their students' learning and their instruction to choose the appropriate strategies based on cognitive, social, and epistemic status to accommodate students' learning needs (Park & Oliver, 2008). Teachers' PCK for students' conceptions can be supported through teachers' understanding of students' prior knowledge, learning difficulties and through evidence of their learning and reasoning. Teachers' sufficient knowledge of students' scientific reasoning can help them identify students' misconceptions and integrate appropriate instructional strategies into science instruction (Park et al., 2011).

Additionally, researchers (Davis & Krajcik, 2005; Beyer & Davis, 2009) focused on the development of educative materials to promote teacher learning- understanding and enacting the knowledge base related to content, instructional strategies, and students' learning. Science teachers

can become enculturated into a range of instructional practices through these educative curriculum materials as they integrate their knowledge in real time situations while making instructional decisions (Davis & Krajcik, 2005). These materials were designed to support the development of teachers' PCK for disciplinary practices allowing them to engage learners in the authentic scientific experiences such as asking questions, developing explanations based on evidence, and communicating and justifying the conclusions.

For example, Schneider (2013) conducted a single case study to examine an elementary science teacher's interaction with the educative materials whether they could strengthen teacher's knowledge and abilities while implementing the inquiry-based activities. The teacher's understanding and interpretation of the educative materials influenced her PCK in different aspects. The teacher focused on integrating open-ended questions, the investigations and hands-on activities through utilizing 5E instructional model and "Predict-Observe-Explain (POE)" learning cycle to scaffold students' learning while they were working in groups and doing investigations through making students' thinking visible and eliciting and exchanging their ideas. As such, development of educative materials should promote the development of PCK and address the challenges of teachers and specific instructional strategies to be linked to teacher's prior experiences and students' learning.

Osborne (2014) argued, "the process of empirical inquiry cannot exist in isolation from the theories that it seeks to test, the analysis and interpretation of the data, and the arguments required to resolve the conflicting interpretations" (p. 579). Osborne made a case for the process of science to involve not only cognitive aspects of knowledge construction but also social and epistemic aspects to engage students in scientific practices. Students need to understand how and why scientific knowledge is constructed, critiqued, and refined in diverse contexts to make sense of the

phenomena and make informed decisions through focusing on the analysis and interpretation of the data and its role in the social construction of scientific knowledge. In response to this, teachers need to be competent in the particular subject content and inquiry practices to teach and translate this knowledge to design lessons and apply teaching approaches and strategies to make the content accessible to students. Science teachers should develop an understanding of the nature of scientific practices to successfully engage students in these practices, particularly argumentation.

PCK of argumentation. Effective teaching begins with an understanding of what students needed to learn and how a topic would be taught. *The Framework for Science Education* suggests, “Science is not just a body of knowledge that reflects current understanding of the world; it is also a set of practices used to establish, extend, and refine that knowledge” (NRC, 2012, p. 27). Reform documents address students’ enculturation into scientific practices, particularly argumentation to support them in constructing evidence-based explanations, identifying the strengths and weaknesses of each other’s arguments using their reasoning, and engaging in the critique of knowledge claims through collaborative work (NGSS Lead States, 2013). In line with this suggestion, teachers need to develop PCK of argumentation to incorporate scientific argumentation into a science classroom. Teachers need to develop knowledge of both structural and dialogic processes as prominent aspects of PCK of argumentation to promote students’ engagement in this practice and integrate appropriate instructional practices based on students’ needs such as “understanding how the data supports the claim and clarifying the science concepts to support their claims” (McNeill et al., 2016, p. 280).

In particular, by having the sufficient knowledge of structural aspects of argumentation, teachers can evaluate students’ writing and oral discussions to enhance the quality of evidence and reasoning components (Knight-Bardsley & McNeill, 2016; McNeill & Knight, 2013;

McNeill et al., 2016). Furthermore, teachers should also develop knowledge base about dialogic interactions in terms of competing claims and student interactions (McNeill et al., 2016) to promote the construction and critique of arguments and evaluate the strength of the alternative claims through exchanging and elaborating on each other's ideas during a lesson- either a lecture, small group discussion or whole-class discussion.

Research addressing teacher knowledge of student conceptions for argumentation focused on teachers' understanding of learning goals or requirements for students' learning and their challenges in engaging in this practice regarding both argument structure and dialogic process. Teachers should be aware of the areas that students need support. Berland and Reiser (2009) indicated that students have difficulty with many aspects of scientific argumentation including understanding the goals and norms of scientific argumentation and what counts as science in oral and written communication. For the structural elements of an argument, students struggled with gathering and analyzing data as evidence to support a claim, backing up that link between the claim and evidence by including the appropriate scientific principles and providing alternative claims to refute a claim (Choi et al., 2015; Evagorou & Osborne, 2013; McNeill et al., 2006; Sampson et al., 2013). Studies also found that students had difficulty in using appropriate evidence (McNeill & Krajcik, 2008; McNeill et al., 2016), providing high-quality evidence for their claims (McNeill et al., 2016; Sandoval, 2003; Sandoval & Millwood, 2005) while talking and writing, and revising their claims based on new evidence (Berland & Reiser, 2009). Students might also rely on their personal views as evidence to conclude (McNeill et al., 2006).

Moreover, students might provide inaccurate or irrelevant justification or reasoning in both oral and written arguments (Berland & McNeill, 2010; Knight-Bardsley & McNeill, 2016; McNeill et al., 2006; Sampson et al., 2013). Students had the most difficulty in justifying why

their evidence supports their claiming using appropriate scientific principles (McNeill et al., 2017), and students' content knowledge influenced their construction of reasoning (Sadler, 2004). Additionally, studies rarely addressed students' challenges in the dialogic aspect of argumentation. Sampson and colleagues (2013) found that students had difficulty in communicating their ideas as students did not use scientific principles to make sense of their observations or as a way to critique and persuade others about the validity or acceptability of a potential explanation. They also struggled with articulating and defending their claims (McNeill et al., 2006; Sadler, 2004) and critiquing others' ideas (Berland & Reiser, 2011).

While selecting the appropriate instructional strategies, teachers should consider both the argumentation question and the desired student outcome to develop an appropriate classroom context for scientific argumentation (McNeill & Knight, 2013). Teachers should provide students with an opportunity to justify and critique claims with evidence and reasoning strategies to enhance students' conceptual understanding. Empirical research suggested some instructional strategies to support the integration of argumentation into science learning. For example, Gonzalez-Howard, McNeill, and Ruttan (2015) suggested that teachers could engage students in argument through evidence by using three strategies: discussing the meaning of the word or phrase related to argumentation, doing a think-aloud to model appropriate language to use during a task, and simplifying a complex claim by identifying key concepts. Moreover, Simon and colleagues (2006) recommended encouraging students to consider a counter argument through questioning such as "Can anyone think of anything that somebody might say to oppose that? What might someone say which makes that argument a bit flawed?" Other researchers considered integrating small tasks to promote students use of argumentation: concept cartoons to give a situation (Cavegnetto, 2010), making an analogy (Crippen, 2012) or use of anomalies

(Roychoudhury & Rice, 2010), competing theories (Osborne et al., 2004), providing second-hand data through data collected by other individuals or simulations to change the variables (Berland & McNeill, 2010), and discrepant events (Sampson & Clark, 2009).

Studies also considered supporting students' use of argumentation as well as higher order and metacognitive thinking during the small group and whole class discussions. For instance, teachers focused on questioning strategies to support dialogic interactions; for example, using open-ended questions supported students in the use of argumentation (Berland & Reiser, 2009; McNeill & Pimentel, 2010). Small group discussions were supported through jigsaw activities (Jiménez-Aleixandre & Pereiro-Muñoz, 2005; Osborne et al., 2013; Sadler, 2006), hands-on activities (Roth & Garnier, 2007), or think-share-pair activities (Choi et al., 2015). Osborne and colleagues (2013) considered integrating video-based exercises focusing on the use of argument to develop teachers' knowledge of argument structure and provide the examples of good and bad arguments. Moreover, research focused on scaffolding writing process through giving structured support or writing frame to explain claim, evidence, and reasoning (Choi et al., 2015; McNeill et al., 2006; Simon et al., 2006) and modeling how to provide evidence and reasoning to support the claim (Choi et al., 2015; McNeill et al., 2006) through writing or speaking.

PCK is a complex and multidimensional construct (Shulman, 1986; Smith & Banilower, 2015) and includes both domain-specific PCK related to the SMK within a particular discipline (e.g. chemistry) and topic-specific PCK that a topic is introduced differently for a subject matter (e.g. different representations of thermodynamics concept in physics and chemistry) (Smith & Banilower, 2015; Van Driel et al., 1998; Veal & MaKinster, 1999). Teachers need to be competent in the particular subject content to teach and translate this knowledge to design lessons and apply teaching approaches and strategies to make the content accessible to students

based on their needs (Loughran et al., 2006). However, teachers' PCK is an implicit tool and difficult to assess (Kind, 2009). Various methods have been used to elicit teachers' PCK. First, Loughran and colleagues (2006) developed open-ended tasks, content representations (CoRes), and professional and pedagogical experience repertoires (PaP-ers), which were found successful to capture teachers' knowledge of content, pedagogy on knowledge of students' conceptions, and instructional strategies. Interviewing is another strategy to probe teachers' PCK through instructional episodes (Smith & Banilower, 2015). Second, Schneider and Plasman (2011) described the PCK as "knowledge of teaching used and developed within practice" (p. 211) and made a case for eliciting teachers' PCK through observation. Lastly, McNeill and colleagues (2016) developed and validated an assessment focusing on science teachers' PCK of argumentation, which referred to teachers' knowledge of argument structure and dialogic process on both knowledge dimensions addressing student conceptions and instructional strategies.

According to Desimone (2009), continuous and intensive professional development programs may support teacher learning to improve their knowledge and practice regarding argumentation. Teachers' engagement in the professional development workshops may enhance their knowledge of student conceptions and instructional strategies for argumentation through analyzing student work, sharing their analysis for discussion, and reflecting on their implementation of argumentation. With a knowledge-for-action approach, McNeill and Knight (2013) worked with 70 science teachers to improve their PCK of argumentation through the research and evaluation systematically. Through participating in three workshop series- fifteen hours in total, teachers could develop a strong understanding of evidence, claim, and reasoning components to evaluate students' writing, but the translation of this knowledge into classroom practice was challenging, particularly for the reasoning component. Teachers less likely focused

on how students supported their claims with evidence or the nature of interaction during classroom discussion; instead, they mostly focused on students' understanding of the science content. Teachers' lack of PCK of argumentation influenced the design of their task and development of an argumentation question. This study suggested the plan of more extended professional development programs and educative curriculum materials to support teacher learning to teach through argumentation and translate their knowledge into classroom instruction to enhance student learning.

In a recent study, McNeill and colleagues (2017) examined the enactment of educative curriculum materials and how they influenced teachers' decision making to support students' learning around scientific argumentation. Participants were ten in-service teachers teaching either fifth or sixth-grade science, who enacted two different six-week unit lessons. Data was collected through lesson artifacts, video-recordings, and teacher interviews. The results indicated that participating teachers had different understandings of argumentation demonstrated in their classroom instruction and curricular choices based on their prior experiences. The study presented two cases as examples for high-quality and low-quality argumentation instructions to discuss the factors influencing teachers' decision-making around the enactment of curriculum materials. High-quality argumentation instruction addressed teacher's keen understanding of argumentation as an epistemic practice aligned with the curriculum materials. The teacher approached the prior teaching experiences as problematic, reflected in the enactment of the curriculum materials rather than following the instructions verbatim. This teacher used questioning strategies to provide an opportunity for students to evaluate the validity of multiple claims to develop the firm understanding of the science content. Low-quality argumentation

instruction occurred when the teacher focused on surface-level features of argumentation and did not integrate the social construction of knowledge claims through critique and evaluation.

The design of educative curriculum materials aimed to support teachers' learning in argumentation instruction and understand how teachers' interaction with those curriculum materials could improve their PCK of argumentation and enactment. Marco-Bujosa and colleagues (2017) utilized the sense-making framework to explore how teachers' use of educative curriculum materials supported teachers' argumentation instruction and the development of PCK of argumentation. Data from five middle school teachers were collected through videos of teacher enactment, teacher interviews, and pre- and post- PCK of argumentation assessments. The results demonstrated that teachers had different learning outcomes from the same educative curriculum materials due to the differences in their goals, knowledge of argument structure and dialogic process, and particular learning context. Teachers' goals in using the educative curriculum materials served as the determinant factors of teachers' enactment. For example, teachers with high-alignment in enactment were aligners of the curriculum and demonstrated higher learning gains in parallel to their PCK of argumentation; these teachers rarely modified, skipped curriculum activities or added new activities. However, teachers, who had low-alignment in the enactment, were the adapters of the curriculum, and they equally aligned, modified, and skipped the activities on the curriculum materials. One of these teachers indicated improvement in her PCK of argumentation by using the curriculum materials. This teacher's use of curriculum materials supported her learning about argumentation, whereas another teacher's use of curriculum materials did not support her learning about argumentation.

Factors Influencing the Implementation of Argumentation

Despite the reform efforts as mentioned in the previous sections, teachers continue teaching science around teacher-centered talk and promoting low-quality argumentation instruction (e.g., McNeill et al., 2017; Pimentel & McNeill, 2013). One area of research focused on examining the role of teacher beliefs that might influence or be related to the development of knowledge and practices, interpretation of curriculum, choices of assessments as well as their students' learning (Jones & Leagon, 2014). However, not many research studies have been conducted exploring teachers' beliefs about argumentation and their influence on the implementation and students' learning. For example, McNeill, Pimentel, and Strauss (2013) explored the impact of 22 teachers' beliefs about curriculum use on their students' learning. The study had a quasi-experimental design with students' pre- and post- assessments, teacher surveys referring to beliefs about curriculum use and instructional practices. The results indicated a variation among the teachers, who enacted the same inquiry-oriented science curriculum. The findings highlighted the linearity between students' engagement in group work and less lecturing and greater learning gains. The study suggested that teachers needed greater support to shift their beliefs about teaching science to promote students' engagement in argumentation to have them construct arguments and critique alternative claims through using evidence and justification.

A more recent study by Knight-Bardsley and McNeill (2016) focused on examining how five middle and elementary school teachers' PCK of argumentation and beliefs changed and reflected in their classroom practices over the course of fifteen-hour professional development. Data was collected through pre- and post- PCK of argumentation assessment, video-recordings of classroom instruction, and teacher interviews to examine teacher beliefs. At the beginning of the study, all teachers had similar PCK of student conception scores. The teachers, whose

instructional practices aligned with the scientific argumentation, had more sophisticated beliefs about argumentation addressing the role of evidence and reasoning or role of counterargument and experienced improvement in their PCK of argumentation. These teachers' reflection on their practices resulted in improvements on their beliefs and PCK of argumentation. However, teachers, who adapted and renamed the current practice as argumentation, continued using their prior teaching experiences and used the language of argumentation as a claim, evidence, and reasoning framework without utilizing the resources provided by the PD program. These teachers' beliefs focused on the use of specific words such as "thinking, describing, analysis" to explain a phenomenon rather than construction and critique of claims using evidence. The adapting and renaming the current practice as argumentation resulted in minimal changes in teachers' PCK of argumentation, beliefs, and instructional practices. This study suggested the design of sustained and intensive professional development programs, which might explore the ways of improving pre-service and in-service teachers' PCK of argumentation and beliefs to promote high-quality argumentation instruction to enhance student learning.

Besides teachers' beliefs, an area of research also focused on other factors influencing the argumentation instruction. Marco-Bujosa and colleagues (2017) argued that the personal and contextual factors played a role in teachers' incorporation of argumentation instruction. The teachers with high learning gains mostly considered personal factors including fidelity of implementation, preparation, and access/equity issues, but the teachers with low learning gains focused on the contextual factors such as class time, curriculum, and collaboration activities as the influencing factors on the enactment.

In a similar study, McNeill and colleagues (2016) explored the factors influencing the teachers' implementation of argumentation through survey and phone interviews. The results

indicated that teachers' views of argumentation served as effective on the argumentation instruction. They defined argumentation referring to the role of evidence, the consideration of multiple claims, and the importance of critiquing, and they also referred to the broader argumentation goals such as citizenship issues, scientific literacy, and critical thinking. Moreover, they discussed different characteristics of students including their background, abilities, and literacy skills (reading, writing, and talking) as affecting the design of instruction. Lastly, the teachers approached the argumentation regarding policy, standards, and assessments differently. Some teachers considered standards and tests as focusing on memorization of facts not aligned with the goals of argumentation, whereas the teachers, who adopted the Common Core standards for English-Language Learners (ELLs) discussed the alignment of argumentation instruction with standards and state tests. For example, one teacher stated, "These skills are highly tested in sixth grade English-Language Arts." These teachers supported the argumentation instruction as aligned with policies, standards, and assessments to enhance student learning.

Summary. Empirical research discussed above examined the ways teachers utilized scientific argumentation and the instructional supports to enhance their knowledge and practice and student learning (e.g., Christodoulou & Osborne, 2013; Martin & Hand, 2009; McNeill & Krajcik, 2008). Researchers suggested the original or modified version of Toulmin's Argumentation Pattern as the structure of an argument; for example, Sampson and colleagues (2011) utilized the model addressing claim, evidence, and justification framework. The researchers also focused on the dialogic aspect of argumentation that individuals engaged in debate in groups or in a whole class discussion, which promoted student-student interaction and alternative ideas. These studies suggested seeing argumentation as a way to build knowledge through collaboration, constructing knowledge claims, and reaching consensus as well as critiquing other's ideas and defending their

claims rather than focusing on the facts or right answers from the teacher or textbook. To establish a classroom instruction supporting students' learning through argumentation, researchers developed instructional models such as Argument-Driven Inquiry (ADI) model (Sampson et al., 2011), Science Writing Heuristics (SWH) (Wallace et al., 2004), and Scientific Explanation Framework (McNeill et al., 2006) to scaffold the use of argument structure and to encourage students' participation into scientific practices such as writing, accountable talk, or peer review in groups, in a whole class activity or individually.

Empirical studies also discussed the role of teachers' knowledge and practices around argumentation to enhance students' learning. An area of research aimed to explore teachers' successes and challenges that might provide an avenue to incorporate argumentation into science instruction and facilitate learners' engagement in argumentation (Crippen, 2012; Sampson & Blanchard, 2012). For example, teachers had difficulty in providing relevant and high-quality evidence and reasoning conceptions as well as enhancing student voice and increasing the multiplicity of ideas. To address teachers' challenges, researchers particularly investigated the extent of science teachers' promotion of epistemic discourse and argumentative writing with different methodologies (Choi et al., 2013; Gray & Kang, 2014; McNeill & Pimentel, 2010; Swanson et al., 2013). These studies suggested that teachers' understandings around argumentation might influence what instructional strategies they utilized to accommodate students' learning needs while incorporating argumentation into instruction.

Additionally, recent studies emphasized the role of educative curriculum materials and professional development programs to support teacher learning around argumentation. They aimed to encourage science teachers to develop PCK of scientific argumentation addressing teacher knowledge of student conceptions and instructional strategies for argumentation regarding structural elements and dialogic aspect. An area of research utilized educative materials to

investigate how these instructional supports impacted the development of and relationship between PCK of argumentation, beliefs, and their practice (Gonzales-Howard et al., 2017; Knight-Bardsley & McNeill, 2016; McNeill & Knight, 2013; McNeill et al., 2017) and what other factors, contextual and personal factors influencing teachers' knowledge and argumentation instruction (Marco-Bujosa et al., 2017; McNeill et al., 2017).

Studies on PCK of argumentation indicated the need for developing teacher expertise to evaluate students' arguments to identify their strengths and weaknesses and integrate appropriate instructional strategies to accommodate students' learning about science concepts, scientific inquiry, and knowledge specific to argumentation (e.g. Davis & Krajcik, 2005; Lee & Luft, 2008; Magnusson et al., 1999; Osborne, 2014). McNeill and Knight (2013) suggested that teachers should be exposed to argumentation instruction over a longer than three months to be able to successfully develop their PCK of argumentation and have more sophisticated beliefs to promote high-quality argumentation in practice. Teachers might need minimum two-year experience with argumentation instruction to effectively promote student learning (Osborne et al., 2013).

Considering the results of the studies discussed in this section, this study will explore urban science teachers' PCK of argumentation around knowledge of student conceptions and instructional strategies for both argument structure and dialogic process.

Furthermore, researchers focused on exploring teacher beliefs that might determine how teachers interpreted, understood, and organized the information; however, they might also filter teachers' understandings and practice (Pajares, 1992). Crawford (2007) argued that teachers' resistance to change their teacher-centered practices might be linked to their knowledge of science content, pedagogical practices as well as their beliefs about teaching and learning science; and there might be reciprocal relationship between teachers' beliefs and knowledge shaping the development of each construct as well as pedagogical practices. Teachers' epistemological beliefs

are a subsystem of a larger belief system consisting of domain-general and domain-specific beliefs that may have a mediating role in how teachers processed information. In other words, teachers' epistemological beliefs influence how they construct and evaluate knowledge and enact the argumentation instructional models with fidelity (Jones & Carter, 2007; Liu & Roehrig, 2017). The following section will address how the educational research has addressed teachers' epistemological beliefs, in particular, domain-general and domain-specific epistemological beliefs.

Epistemological Beliefs

Knowledge and Beliefs. Teachers' educational beliefs are considered as part of a general belief system connected to teachers' perceptions, planning, decisions, and, in turn, their practices and student learning outcomes (Muis, 2007; Pajares, 1992). As such, teachers' personal epistemologies influence what they teach, how they process information, and how they assess students' learning (Fives & Buehl, 2017). The term personal epistemology describes teachers' beliefs from a psychological perspective and addresses individuals' thinking and beliefs about knowledge and knowing (Hofer, 2004; Hofer & Pintrich, 1997). Teachers' personal epistemology is an important aspect of their instructional beliefs (Pajares, 1992), and examining teachers' epistemology contributes to understanding how origins of a belief system or specific beliefs (i.e., beliefs about nature of science or beliefs about teaching and learning or beliefs about self) influence the instructional practice (Jones & Carter, 2007; Jones & Leagon, 2014).

The study of personal epistemology is important to conceptualize the system of teachers' beliefs, how one comes to know, and how knowledge is defined, constructed, and evolved to frame further research on pedagogical beliefs (Hofer, 2004; Hofer & Pintrich, 1997; Jones & Leagon, 2014). However, Pajares (1992) argued, "Distinguishing knowledge from beliefs is a daunting undertaking" (p.309). Beliefs and knowledge have been described differently by different researchers. Rokeach (1968) defined knowledge as part of a belief system, which involved cognitive

components representing knowledge, affective components arising emotion, and behavioral components causing an action. Nisbett and Ross (1980) thought beliefs and knowledge were the same constructs, whereas Nespor (1987) suggested that beliefs, as an affective component, operated independently from the cognition associated with knowledge. Pajares (1992) stated, “Belief is based on evaluation and judgment; knowledge is based on objective fact” (p. 313).

Science education literature also addressed the distinction between knowledge and beliefs. Gess-Newsome (1999) noted knowledge as “evidential, dynamic, emotionally-neutral, internally structured, developed with age and experience” (p. 55) and beliefs as “including both affective and evaluative functions, acting as information filters and impacting how knowledge is used, organized, and retrieved” (p. 55). In addition, Southerland, Sinatra, and Matthews (2001) separated scientific knowledge from personal knowledge, in which the former addressed the justified information through empirical evidence and as subject to change, whereas the latter was a subjective and static construct. Table 2 summarizes the relationship between beliefs and knowledge, whether they are defined as stable or dynamic or with the perspective of an individual or a system.

Epistemology and Epistemological Beliefs. Beliefs about the nature of knowledge and knowing are synonymously used as “personal epistemology” and tightly interwoven into epistemological beliefs (Hofer, 2001). Epistemology is interested in the nature, sources, and limits of human knowledge, and the processes by which such knowledge is verified, justified or argued (Buehl & Alexander, 2001; Hofer, 2004; Hofer & Pintrich, 1997). The term “epistemology” derived from the Greek word *episteme* (i.e., knowledge) and *logos* (i.e., explanation) has been used as a philosophical inquiry (Buehl & Alexander, 2001). Dewey (1916) was concerned about what it meant to know and the process of knowing as well as how teaching and learning process might transform individuals’ beliefs or how beliefs influenced the instructional practices. From an educational perspective, Hofer and Pintrich (1997) addressed epistemology as the development of

individual's beliefs about nature of knowledge and knowing in the process of teaching and learning. The authors reported that epistemological beliefs had been defined in different ways considering the labeling of the construct, the boundaries defining what was included or excluded, and the nature of the relationship between epistemological thinking and general thinking across various models.

Table 2

The relationship between knowledge and beliefs (modified from Fives & Buehl (2012))

Definition	Stable or dynamic	Knowledge and Belief	Individual or system
The structure of belief systems was organized in a psychological, but not logical form. Some beliefs are more central than others, and that central beliefs are more difficult to change. Knowledge is part of a belief system, which involved cognitive components representing knowledge. (Richardson, 1997; Rokeach, 1968)	Stable	Related	System
Beliefs and knowledge are the same constructs. "People use certain knowledge structures in approaching judgment tasks. These include relatively propositional structures such as theories and beliefs (Nisbett & Ross, 1980, p. 42)."	Stable	Same	Individual
Belief systems rely on affective components than the knowledge systems, which include the forms of cognition (Nespor, 1987)	Stable	Distinct	System
"Belief is based on evaluation and judgment; knowledge is based on objective fact" (Pajares, 1992)		Distinct	Individual
Knowledge is "evidential, dynamic, emotionally-neutral, internally structured, developed with age and experience" (p. 55); beliefs include "both affective and evaluative functions, acting as information filters and impacting how knowledge is used, organized, and retrieved" (Gess-Newsome, 1999, p. 55).	Belief stable; knowledge dynamic	Distinct	System
Scientific knowledge is different from personal knowledge. Knowledge addresses the justified information through empirical evidence and as subject to change; belief is a subjective and static construct (Southerland, Sinatra, & Mathews, 2001).		Distinct	Individual

For example, epistemological beliefs have been studied using different labels in the earlier studies: epistemological positions (Perry, 1970), women's ways of knowing (Belenky, Clinchy, Goldberger, & Tarule, 1986), epistemological assumptions (Magolda, 1992, 2002), epistemological thinking (Kuhn & Weinstock, 2002), and personal epistemology (Hofer, 2001). Due to different labels in the literature, this study will address different terms such as "personal epistemology," "epistemic beliefs," and "epistemological beliefs" interchangeably as "epistemological beliefs."

Table 3 represents the definitions and resources for different terms of epistemological beliefs.

Table 3

Different terms for "epistemological beliefs" in the literature

Term	Definition	Source
Epistemological positions	The development of individuals' beliefs about nature of knowledge	Perry, 1970
Epistemological assumptions	Ways of knowing about the nature, limits, and certainty of knowledge	Baxter Magolda, 2002
Epistemological thinking	Beliefs about knowledge and knowing	Kuhn, Cheney, & Weinstock, 2000
Epistemological beliefs	Beliefs about nature of knowledge and learning depending on certainty, source, justification, acquisition, and structure	Duell & Schommer-Aikins, 2001; Schommer, 1990
Epistemic beliefs	Beliefs about nature of knowledge and knowing	Hofer, 2000; Hennesey, Murphy, & Kulikowich, 2013
Personal epistemology	Beliefs about knowledge and knowing: how knowledge is constructed, how knowledge is evaluated, where knowledge resides, and how knowing occurs	Hofer, 2001
Epistemological theories	Individuals' ideas about knowledge and knowing as organized as personal theories	Hofer & Pintrich, 1997

Developmental and multidimensional paradigms. Researchers have begun to study epistemological beliefs with two paradigms: developmental (Kuhn, 1991; Perry, 1970; Piaget, 1970) and multidimensional (Schommer, 1990). The primary work on epistemology and epistemological beliefs was the Piaget's genetic epistemology concerning "the study of knowledge as a function of its development" (Piaget & Duckworth, 1970, p. 13). Piaget's conceptualization of

knowledge development was defined as an active process rather than a passive state and knowing included the transformation of the information through equilibration. The work on genetic epistemology suggested the concept of equilibration as an active self-regulatory process involving the interaction between the assimilation and accommodation in a sequence of development (Piaget, 1970). Piaget (1970) defined assimilation as a process of incorporating the new information into pre-existing beliefs, whereas accommodation took place when new structures were built to understand information (Hofer & Pintrich, 2002; Muis, 2004).

Piaget's notion of epistemology has influenced the examination of epistemological beliefs through a patterned sequence of development (Muis, 2007). The developmental models conceptualized epistemological beliefs as a unidimensional construct that began with an objectivist stance that individuals believed the certainty of knowledge, and followed by a multiplistic position, in which individuals considered uncertainty and acknowledged the alternative ideas. Unidimensional theories have stage-like dimensions; as one dimension develops, the other dimension also develops. Table 4 represents the conceptualizations approaching the epistemological beliefs with a unidimensional approach. The most mature level of epistemological beliefs was defined in different ways such as relativism (Perry, 1970), reflective thinking (King & Kitchener, 1994), constructed knowledge (Belenky et al., 1986), and contextual knowing (Baxter Magolda, 1992), in which individuals think that knowledge was actively constructed and evolving, and knowing was coordinated with justification. Although these studies labeled the levels of epistemological development differently, three labels (absolutism, multiplism, and evaluativism) will be used in the current study as the most common ones across these definitions.

Table 4

Unidimensional conceptualizations of epistemological beliefs (Modified from Hofer, 2001; Deniz, 2017)

	Perry (1970)	Belenky et al. (1986)	Baxter Magolda (1992)	King & Kitchener (1994)	Kuhn (1991)
		Silence			
Stages of Epistemological Development	Dualism	Received Knowing	Absolute Thinking	Pre-reflective Thinking	Absolutist
	Multiplism	Subjective Knowing	Transitional Thinking	Quasi-reflective Thinking	Multiplist
	Relativism	Procedural Knowing	Independent Thinking	Reflective Thinking	Evaluativist
	Commitment to Relativism	Constructed Knowing	Contextual Thinking		

The work of Perry (1970) not only became the source for the developmental models, but also guided the development of multiple dimensionality paradigm for epistemological beliefs. Schommer (1990) thought unidimensionality approach to epistemological beliefs might filter the multiple links between personal epistemology and learning process since this type of paradigm could only address one aspect of beliefs such as the development of beliefs about the justification of knowledge (King & Kitchener, 1994) or beliefs about the certainty of knowledge (Baxter-Magolda, 1992). Schommer (1990) claimed that epistemological beliefs were in a system of more or less independent, but related belief dimensions that were relatively distinct from one another and changed over time. This conceptualization initiated a line of research that linked epistemological beliefs to teaching and learning for the development of questionnaires to assess the individuals' beliefs about the nature of knowledge and learning from a multidimensional approach.

Schommer (1990) developed Epistemological Questionnaire (EQ) including 63 items with 12 subsets of items and five dimensions, and participants responded to the questionnaire on a Likert scale from 1 (strongly disagree) to 5 (strongly agree). Dimensions addressed the individuals' beliefs about the certainty and simplicity of knowledge, the control and speed of learning, and the

source of knowledge. This questionnaire has been used to assess the links between epistemological beliefs and academic performance among students across many grade levels and to relate students' epistemological beliefs to other student variables (such as age/gender, year in school, and parents' educational background) and personal background or unique aspects of learning.

Epistemological beliefs have been primarily measured by questionnaires with Likert-scale responses. Schommer's Epistemological Questionnaire (SEQ) has been utilized as a base and refined depending on the researchers' concerns about the dimensions to assess epistemological beliefs. Jehng, Johnson, and Anderson (1993) eliminated the items about the structure of knowledge and added items related to orderly process and source of knowledge. Schraw, Dunkle, and Bendixen (1995) included the beliefs about the source of knowledge dimension to SEQ to develop "Epistemic Beliefs Inventory (EBI)." Hofer (2001) developed the Epistemological Beliefs Questionnaire (EBQ) addressing four core belief dimensions about knowledge as the certainty of knowledge, the simplicity of knowledge, and beliefs about knowing as the source of knowledge and justification of knowledge. Wood and Kardash (2002) combined items in Jehng et al. (1993) and Schommer (1990) instruments to develop "Epistemological Beliefs Survey (EBS)" addressing five independent dimensions: the speed of knowledge acquisition, structure of knowledge, knowledge construction and modification, characteristics of successful students, and attainability of objective truth.

Buehl (2008) aimed to organize the dimensions of epistemological beliefs suggested by the previous investigations. Epistemological beliefs categorized into two dimensions as beliefs about nature of knowledge and knowing that each included specific dimensions. Beliefs about nature of knowledge addressed "beliefs about simplicity or complexity of knowledge, the degree to which knowledge is isolated or integrated as well as beliefs about the certain or changing nature of knowledge" (p. 100). Beliefs about nature of knowing referred to the process of knowing as well as

controlling and influencing factors. “Process of knowing” was related to the beliefs about “processes that individuals use to acquire, construct, or modify knowledge” (p. 100) including the source of knowledge, the speed of knowledge, justification of knowing, and knowledge construction and acquisition. “Controlling and influencing factors” addressed whether learning was an innate or fixed ability or aspects that could influence learning such as characteristics of students or learning environment. This organized framework is represented in Table 5 (referring to the previously mentioned frameworks having multidimensionality approach to epistemological beliefs) and utilized as a guide in this study to assess participants domain-general epistemological beliefs.

The studies mentioned above utilized Likert-scale surveys to assess individuals’ epistemological beliefs. Brownlee and Schraw (2017) argued that instruments including multiple choices or Likert-scale surveys were found insufficient for not to understand individuals’ epistemological beliefs in-depth. The authors suggested that individuals’ epistemological beliefs should be assessed through multiple methods including open-ended items. For example, observations provided important data to understand teachers’ epistemological beliefs in practice (Duffy, Muis, & Foy, 2017). Interviews (Alexandre, 2017) or stimulated-recall interviews (Edwards, Brownlee, & Berthelsen, 2017), think-aloud protocols (Hofer, 2004), refutational texts (Kienhues, Bromme, & Stahl, 2008), ill-structured problems or dilemmas (King & Kitchener, 1994; Kuhn, 1991), vignettes (Schraw, Olafson, & VanderVeldt, 2011) and reflections (Brownlee, 2001) were the ways that previous studies utilized to develop in-depth understanding of individuals’ domain-general epistemological beliefs. So far, this section has addressed individuals’ domain-general epistemological beliefs; and, next section will focus on the domain-specific epistemological beliefs.

Domain-specificity of epistemological beliefs. The studies discussed in the previous section explored the individuals’ epistemological beliefs with the similarity for different academic domains assumption. This argument was supported by the empirical evidence

Table 5

Organized framework for epistemological beliefs (Modified from Buehl, 2008)

Beliefs about nature of	Schommer (1990)	Jehng et al. (1993)	Schraw et al. (1995)	Hofer (2001)	Wood & Kardash (2002)
Knowledge	- Certain knowledge - Structure of knowledge	Certain knowledge	- Certain knowledge - Structure of knowledge	- Certain knowledge - Structure of knowledge	- Attainability of objective truth - Structure of knowledge
Knowing:					
Process of knowing	Quick Learning	- Quick Learning - Source of knowledge - Orderly process	- Quick Learning - Source of knowledge	- Justification of knowledge - Source of knowledge	- Speed of knowledge acquisition - Knowledge construction and modification
Controlling influencing factors	Innate Ability	Control of knowledge acquisition	Control of knowledge acquisition		Characteristics of successful students

from Schommer and Walker (1995): The authors measured domain-specificity through a domain-general instrument and found that epistemological beliefs were domain independent across mathematics and social science. However, other researchers argued that epistemological beliefs should be assessed with instruments addressing domain-specific epistemological beliefs relative to the academic disciplines (Buehl, Alexander, & Murphy, 2002; Hofer, 2000) or specific to domain of study classified as well-structured or hard domains such as mathematics or physics or ill-structured or soft domains as psychology, history, or sociology (Muis et al., 2006). More specifically, individuals' epistemological beliefs might differ across domains (between-subject designs; interindividual) as well as individuals might hold different beliefs about different domains (within-subject designs; intraindividual) (Muis, 2004).

Buehl, Alexander, and Murphy (2002) and Hofer (2000) hypothesized that domain-specific epistemological beliefs might be recognized when they were assessed through domain-specific measures relative to the academic disciplines, such as science or mathematics or social sciences. Hofer (2000) explored first-year science and psychology majors' epistemological beliefs through a discipline focused questionnaire. Participants were 300 students attending a psychology class and responded the questionnaire twice: once considering each item for psychology and once for science. The study found significant differences for science and psychology majors' epistemological beliefs. Students thought that scientific knowledge was certain, unchanging, and less justified by personal experience; but in psychology, personal knowledge was the basis of justification for knowing. In Buehl, Alexander and Murphy (2002)'s study; the authors developed another domain-specific questionnaire focusing on mathematics as well-structured area and history as ill-structured area. Participants were 633 undergraduate students attending a variety of classes from different majors. All participants responded to the domain-specific questionnaire, and a subset of them also took

Schommer's Epistemological Questionnaire for comparison. Results of the study provided the support for the notion that epistemological beliefs were highly-domain specific. Students believed the acquisition of knowledge in mathematics was more integrated and required more effort than the acquisition of knowledge in history.

Hofer (2000) and Buehl et al. (2002) provided evidence for the discipline-specific approach to epistemological beliefs. In a comprehensive review, Muis and colleagues (2006) elaborated on these arguments and reported that the empirical studies highlighted the evidence for domain-specificity of epistemological beliefs that might be shaped through instructional context and/or structure of the domain. These studies highlighted the significance of exploring domain-general and domain-specificity issues to understand the nature of these concepts and to investigate how these constructs interacted with each other and with other constructs such as beliefs about teaching and learning. In particular, these studies aimed to understand how domain-general beliefs influenced the development of domain-specific beliefs. The following section will discuss how epistemological beliefs, in particular, how domain-specificity of epistemological beliefs are addressed in science education.

Science Education and Epistemological Beliefs

Educational researchers have explored teachers' beliefs about specific aspects such as curriculum, beliefs about teaching and learning in a more general sense, and their beliefs about science, scientific knowledge, science teaching and learning, and science curriculum (Van Driel, Bulte, & Verloop, 2007). Teachers' beliefs about science and scientific knowledge have been essential to understanding how they conceptualized and approached science teaching (Lee & Tsai, 2011; Pajares, 1992; Tsai, 2008). In other words, teachers' epistemological beliefs involved their understanding of the epistemic nature of a discipline such as their beliefs about science or scientific

knowledge and beliefs about science teaching and learning. Teachers' instructional strategies and decision-making or planning were associated with their epistemological beliefs (Yang, Chang, & Hsu, 2008), and teachers needed to develop sophisticated epistemological beliefs that might guide to their pedagogical beliefs and strategies to shape the classroom environment and instruction to promote the development of students' epistemological beliefs (Lee & Tsai, 2011). Feucht (2017) suggested that teachers' domain-general and domain-specific beliefs were important aspects of teacher beliefs and related to each other; it was necessary to examine how they interacted with each other and how they influenced teachers' instructional practices and students' learning.

There was empirical evidence about domain-general and domain-specificity of epistemological beliefs, but there was a lack of conceptual clarity about how teachers' epistemological beliefs were related to their beliefs about teaching and learning (Hofer & Pintrich, 1997). Brownlee (2001) argued that epistemological beliefs system involved both core and peripheral beliefs as separate and independent dimensions from each other. Core beliefs are considered as individuals' beliefs about knowledge and knowing and more stable and difficult to change (Barkatsas & Malone, 2005; Hofer & Pintrich, 1997; Rokeach, 1968). Sinatra (2016) also made a case for the stability of epistemological beliefs as the content of individuals' cognition that might change only through targeted and carefully designed interventions. Moreover, peripheral beliefs are considered as beliefs about teaching and learning subject to change depending on a specific learning task or context (Cross, 2009; Hofer & Pintrich, 1997). The studies on peripheral beliefs revealed that teachers held interrelated domain-general and domain-specific beliefs about teaching and learning (Belo et al., 2014; van Driel et al., 2007). For example, teachers possessed domain-general beliefs about teaching and learning addressing the goals of education (e.g. to disseminate knowledge to students or to improve students' capabilities and stimulate their personal

development) and the regulation of learning processes (e.g. students passively receiving and accumulating knowledge or actively constructing knowledge) (Belo et al., 2014; Tsai, 2008). Teachers' domain-specific beliefs about teaching and learning were linked to their beliefs about teaching and learning a specific topic such as chemistry or physics and their beliefs about goals of physics curriculum with the emphasis of fundamental physics, technology, society, and scientific knowledge development (Belo et al., 2014; van Driel et al., 2007).

Teachers' beliefs about teaching and learning science have been categorized as teacher-centered and student-centered or conceptual beliefs in science education literature. Teachers with teacher-centered beliefs considered that the best way to teach science was through transferring knowledge from teacher to students and that learning science involved repetition and memorization rather than the active construction of knowledge through group work activities and discussions (Tanase & Wang, 2010; Tsai, 2008). Teachers with teacher-centered views believed that science should be taught in a well-organized classroom through limited interaction with students or limited student participation and via giving specific directions to keep students on task (Brown & Melear, 2007; Levitt, 2001). However, teachers with student-centered beliefs thought that students could learn through variety of ways such as engaging in hands-on activities, being active participants in learning science (e.g., collaborative work, peer teaching, or discussion), and having positive attitudes toward science and meaningful learning experiences (Brown & Melear, 2007; Levitt, 2001; Tsai, 2008).

The studies above addressed science teachers' epistemological beliefs considering domain-general epistemological beliefs and the constructivist and traditional approaches to teaching and learning in general and science in particular. Science education researchers also studied individuals' epistemological beliefs about how scientific knowledge was constructed and

developed. They highlighted the significance of teachers' knowledge of science and scientific knowledge as the essential aspect to understand their approach to teaching and learning science (Brickhouse, 1990; Lederman, 1999). Science is described as "body of knowledge, method, and way of knowing" (Lederman, 2007, p. 833) and scientific knowledge refers to "a particular kind of knowledge with its own sources, justifications, ways of dealing with uncertainties, and agreed-on levels of certainty" (NRC, 2012, p. 251). Lederman (2007) defined nature of science (NOS) from the philosophical perspective as "epistemology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development" (p. 833). On the other hand, epistemological beliefs are studied from the perspective of individual in psychology as personal epistemology, and domain-general and domain-specificity of personal epistemologies have been studied by many researchers that provided empirical evidence for how they influenced teachers' instructional practices and students' learning (Hofer, 2008).

Science educators defined epistemology as the study of a specific discipline by the philosophers of science to discuss "the logical and philosophical grounds upon which scientific claims are advanced and justified" (Sandoval, 2005, p. 635). Referring to a specific form of knowledge and knowing, scientific knowledge was defined as the justified information through empirical evidence and subject to change, which was constructed through a process different from other forms of knowledge (Sandoval, 2005; Southerland et al., 2001). Tsai and colleagues (2008) focused on studying scientific epistemological beliefs as the domain-specific aspect of individuals' personal epistemologies referring to their beliefs about nature of scientific knowledge and nature of knowing science (McDonald, 2016). Sandoval (2005) made a case for this distinct definition about scientific epistemology to address learners' practical epistemologies, which students held about their own learning and construction of their own

knowledge in science as different from a formal epistemology that learners possessed about how scientific knowledge is developed by professional scientists. Even though studies approached epistemology of science from different perspectives as nature of science, scientific epistemological beliefs as formal or practical epistemologies, throughout this study, teachers' epistemological beliefs about science and scientific knowledge (domain-specific beliefs) will be defined as teachers' knowledge of nature of science (NOS), and the terms NOS and scientific epistemological beliefs will be used interchangeably.

Recent reform documents emphasize the significance of developing individuals' understanding of subject matter, nature of science (NOS), and scientific inquiry (SI) to enhance the scientific literacy (NRC, 2012). In other words, besides the content knowledge, individuals need to develop epistemological views about science to understand the nature of knowledge and how it is developed (Bartos & Lederman, 2014; Capps & Crawford, 2013). Within the *Next Generation Science Standards* (NGSS Lead States, 2013), scientific inquiry has been replaced as scientific practices such as engaging in the construction and critique of evidence-based explanations and communicating the results (Lederman & Lederman, 2014).

Across the world, reform documents have emphasized the development of learners' views of NOS and engagement in the scientific practices in teaching different disciplines of science (e.g. ACARA, 2012; NGSS Lead States, 2013; NRC, 2012). Characteristics of scientific knowledge are considered as the aspects of NOS (Lederman & Lederman, 2014) that refers scientific knowledge as tentative evolving with new evidence, empirically-based, theory-laden (subjective, influenced by personal background, biases, beliefs, training etc.), as partly product of human inference, imagination, and creativity, and socially and culturally embedded (Lederman,

2007; Lederman & Lederman, 2014). There are also two additional aspects that address the relationship between observation and inference as well as theory and laws (Lederman, 2007).

Individuals' epistemological beliefs were complex, multidimensional, interactive, developmental, and contextual (Buehl & Alexander, 2006). Deniz (2017) argued that multidimensional and unidimensional approaches to domain-general epistemological beliefs aligned with these aspects of NOS that specific dimensions were related to the aspects of nature of science. For example, attainability of truth is related to subjectivity aspect of science, and certainty of knowledge addresses the tentative aspect of scientific knowledge with a level of sophistication. The author suggested that teachers should develop sophisticated domain-general epistemological beliefs to maintain advanced knowledge of NOS and reflect their epistemological beliefs in practice. In other words, science teachers with naive NOS understandings and domain-general epistemological beliefs ignore or avoid supporting their claims with relevant evidence, focus on the absolute facts, and are close to promoting student interaction and multiple perspectives (Liu & Roehrig, 2017).

Considering these arguments, this study assumed that science teachers should develop high-quality PCK of argumentation, sophisticated epistemological beliefs including both domain-general and domain-specific beliefs to effectively promote science teaching and learning around scientific practices, particularly argumentation through asking scientifically oriented questions, making evidence-based explanations, and communicating and justifying explanations. Teachers in this study participated in a PD program focusing on the argumentation instructional model. This study assumed that science teachers possessed stable beliefs about nature of knowledge and knowing as the professional development did not address their domain-general epistemological beliefs. Furthermore, the study was also interested in teachers' domain-specific beliefs involving knowledge about nature of science (NOS) and beliefs about science teaching and learning. For

teachers' knowledge of NOS, the argumentation instructional model aimed to address science and engineering practices, characteristics of science, disciplinary core ideas, and crosscutting concepts, so that the study assumed that teachers' knowledge of NOS changed through one-year PD program. Even though teachers' beliefs about teaching and learning science was considered as peripheral beliefs and subject to change, this study was interested in teachers' beliefs about teaching and learning science as emerged from the data (rather than focusing on the change). Teachers' beliefs about teaching and learning science were compared to their domain-general epistemological beliefs to prepare an epistemological beliefs profile for each teacher. Next section will provide a review addressing how the literature discussed teachers' epistemological beliefs in general, science teachers' epistemological beliefs, beliefs about teaching and learning science, and knowledge of NOS.

Teachers' Epistemological Beliefs

Researchers were interested in identifying the relation between epistemological beliefs and teaching and learning (e.g., Hofer, 2004; Hofer & Pintrich, 1997; Sinatra & Kardash, 2004). The results of Schommer's studies (Schommer, 1990, 1993) indicated that students' engagement in learning was related to their epistemological beliefs; and teachers' epistemological beliefs may also influence how they teach and their students' epistemologies. There has been limited research on teachers' epistemological beliefs. A study by Chan and Elliott (2004) examined the Hong Kong teacher education students' epistemological beliefs and conceptions of teaching and learning. They utilized a questionnaire adapted from Schommer (1990) to address beliefs about innate/fixed ability, learning effort/process, authority/expert knowledge, and certainty of knowledge. The study found that pre-service teachers held the strong belief in the learning effort and process to acquire knowledge; they did not believe that learning required innate ability, and

knowledge was certain and unchanged. There was a causal relationship between teachers' epistemological beliefs and conceptions of teaching and learning; learning effort and process dimension were negatively related to the constructivist approach. Student teachers tended to believe that hard work and effort was important for learning, but in learning effort, they focused on repetition or memorization to reproduce what was known rather than the construction of knowledge. In a similar study, Cheng, Chan, Tang, and Cheng, (2009) explicated the pre-service teachers' epistemological beliefs about conceptions of teaching. Teachers had much stronger leanings towards constructivist teaching. They emphasized the knowledge as evolving and learning effort rather than the innate ability, but they tended to believe in the authorities as more experienced and convincing. These studies revealed the notion of cultural specificity of epistemological beliefs. Teachers' beliefs that knowledge as acquired through one's effort and learning process in these studies aligned with the traditional Chinese Confucian heritage culture valuing hard work.

Studies also investigated Western teachers' epistemological beliefs in specific dimensions and their relation to their conceptions of teaching and learning (Buehl & Fives, 2009; Braten & Ferguson, 2015; Sinatra & Kardash, 2004). For example, Sinatra and Kardash (2004) examined the relationship between US teacher candidates' epistemological dispositions and their teaching approaches. Data collected through EBS (Wood & Kardash, 2002), "Teaching as Persuasion" survey, and disposition scales. They utilized two dimensions from EBS as the speed of knowledge acquisition and knowledge construction and modification that were related to participants' beliefs about knowledge change and how change occurs. They concluded that teacher candidates, who viewed knowledge as changing and constructed over time in a complex process, tended to believe that learning required effort, thinking deeply about new ideas relating

to the new information, and being involved in the learning process. These teachers considered persuasion as an effective tool to restructure students' thinking and reasoning and to foster their openness to change. In another study, Buehl and Fives (2009) uncovered US pre-service and practicing teachers' beliefs about the source and stability of knowledge through an open-ended questionnaire to understand how these beliefs impacted the teachers' implementation of new approaches. The authors found that teachers' beliefs about the stability of knowledge related to their approach to the question, amount, direction, and quality of change, and the reason for the change in knowledge. Teachers' beliefs about the source of knowledge were related to their college coursework, professional workshops, conferences, content area classes, observational and collaborative experiences, and accumulated findings such as books, research articles, and internet.

In a recent study, Braten and Ferguson (2015) explored Norwegian student teachers' beliefs about the sources of knowledge about instruction and students' learning. They utilized the results of Buehl and Fives (2009) to categorize participants' sources of knowledge as formalized bodies of knowledge (theoretical) such as textbooks, research articles, and official websites and experiential sources (practically-based) such as observational and collaborative experiences. The authors also included social and popular media sources as another category. They found that student teachers relied more on experiential resources rather than formalized bodies of knowledge about instruction and learning. They also relied much less on social and popular media than on experiential sources and even less than theory-based sources of knowledge. In these studies (Braten & Ferguson, 2015; Buehl & Fives, 2009), teachers' beliefs about the stability and sources of knowledge indicated their tendency to explore and employ new teaching approaches through existing literature as well as personal experiences.

Researchers (Brownlee et al., 2011; Walker et al., 2012) are also interested in how teachers' epistemological beliefs change through participating in professional development program or through teacher education courses. There was empirical evidence that teachers' epistemological beliefs changed and became more sophisticated over time as a result of academic experiences through attending one-year method courses (Brownlee, Purdie, & Boulton-Lewis, 2001). A recent study by Brownlee and colleagues (2011) explored how pre-service early child education teachers' epistemological beliefs changed as they attended a method course in one semester focusing on evidence-based thinking and practice, multiple perspectives in ways of knowing, and construction of meaning to promote teaching and learning. Participants were 73 students in the third year of a program; they engaged in explicit reflection on their personal epistemology and learned through modeling of teacher educators' reflection on personal epistemologies. Data collected through pre- and post- Epistemological Beliefs Survey (Kardash & Wood, 2000) addressing beliefs about the structure of knowledge, the speed of knowledge acquisition, knowledge construction, characteristics of student success, and attainability of truth. As qualitative data sources, students responded to open-ended questions and journal reflections to reflect on the content addressing their epistemological beliefs. At the conclusion of the semester, participating teachers' epistemological beliefs become more sophisticated about the structure and integrated knowledge referring to interconnections across topics rather than discrete pieces of information. Participants could also develop improved beliefs about the speed of knowledge acquisition, knowledge as the construction of personal meaning, and view of student success based on innate ability, but they did not improve their beliefs about certainty and attainability of truth at a significant level.

The research on teacher beliefs (e.g., Kagan, 1992; Richardson, 1997) indicated that both pre-service and in-service teachers' previous teaching and learning experiences made their existing beliefs stable- resist to change. Brownlee et al. (2001) assumed that short-term interventions such as teacher education courses might not be effective as consistent long-term interventions to change teachers' epistemological beliefs. However, Tanase and Wang (2010) aimed to challenge this assumption through designing a short-term intervention, a semester-long method course similar to Brownlee et al. (2011), addressing pre-service teachers' epistemological beliefs and beliefs about teaching and learning. With the multiple-case study approach, the authors collected data from four teachers through pre- and post- open-ended questions about nature of knowledge, learning, and teaching, weekly reflections on the readings, participant-created artifacts, and observational notes from classroom participation and micro-teaching. The results indicated that pre-service teachers' initial epistemological beliefs were different from each other: Two teachers held absolutist views, and two teachers had multiplistic views, which were directly related to their beliefs about teaching and learning. For example, one teacher possessed beliefs about nature of knowledge as concrete facts and knowledge as developed through listening to the teacher in the role of the ultimate authority. However, as the teacher shifted her ideas and defined knowledge as actively constructed through exchanging ideas, her beliefs about teaching changed accordingly and defined good teaching as constant reflection. The changes in teacher's epistemological beliefs also reflected in the micro-teaching experience. In parallel to the changes in her beliefs, the teacher, who experienced substantial change, engaged students in hands-on activities and group work through acting as a guide for the construction of knowledge.

In another study, Walker and colleagues (2012) investigated how pre-service teachers' beliefs changed in progression as they completed the teacher education program at an Australian University.

Teachers completed EBS (Wood & Kardash, 2002) at three different time points between 2007 and 2010 and participated in scenario-based interviews. The results indicated that teachers had more sophisticated beliefs about the structure of knowledge and speed of knowledge acquisition towards the final years of the program. They believed that knowledge was integrated rather than involving discrete pieces of information, and learning occurred gradually rather than quickly. As pre-service teachers progressed in their program, they were more likely to believe that knowledge was uncertain, and student's success did not depend on the innate ability. Teachers reported the mediating factors on the development of their epistemological beliefs as gaining further knowledge, exposure to university, developing a more in-depth understanding, experiencing contradictions in theories and opinions, maturation, engaging in reflection, and experiences in the field.

These studies (Brownlee et al., 2011; Tanase & Wang, 2010; Walker et al., 2012) indicated that as pre-service teachers continue teacher education program, they may experience some confusion and disequilibrium. Reflecting on their existing beliefs while acquiring new information facilitates the development of conceptions, and in turn, influences the development of their epistemological beliefs from naïve to sophisticated. Additionally, these studies were the examples of the effectiveness of both long-term and short-term interventions. Even though Brownlee et al. (2011) and Tanase and Wang (2010) studies challenged the assumption that only long-term interventions resulted in the conceptual change on teachers' epistemological beliefs, it is still a question whether these beliefs will be sustained as teachers engaged in different academic experiences in different contexts.

Considering the previous debates on domain-general and domain-specificity of epistemological beliefs, empirical studies also focused on exploring teachers' discipline-specific epistemological beliefs. For example, Chai, Khine, and Teo (2006) explained that student teachers in

the hard domain (science and technology) perceived knowledge as more certain than those in the fields of the soft domain (e.g., humanities, languages, business, and commerce). In another study, Liu and Liu (2011) investigated the prospective teachers' epistemological beliefs about physics and mathematics and revealed their understandings of the tentative, subjective, and empirical aspects of physics and the certainty, objectivity, and logical nature of mathematics. However, teachers were convinced by the authority of scientific and mathematical knowledge rather than considering the role of creativity and imagination and social and cultural factors in science and mathematics. Teachers rarely addressed the intimate relationship between math and physics; the study suggested that teachers also needed to understand how epistemological beliefs about mathematics to promote learning in science.

Moreover, according to Muis and colleagues (2006), individuals' domain-general epistemological beliefs might have an indirect effect on domain-specific beliefs; domain-specific beliefs evolve during the academic years, and as individuals progress through higher levels of education, domain-specific beliefs become more dominant than domain-general beliefs. Schommer-Aikins and Duell (2013) explored whether academic knowledge in mathematics was related to individuals' domain-general and domain-specific beliefs. They found that the more students believed in continuous learning in mathematics, they developed better mathematical problem-solving abilities. However, if students had the minimal mathematical background, their domain-general beliefs would support higher order thinking rather than domain-specific beliefs. When students developed an advanced mathematical knowledge, both domain-general and domain-specific epistemological beliefs became indistinguishable and acted together to promote the higher order thinking.

Summary. The studies reviewed in this section focused on teachers' epistemological beliefs with different purposes: to explore the relationship between specific dimensions of epistemological beliefs and conceptions of teaching and learning (e.g. Buehl & Fives, 2009; Braten & Ferguson,

2015; Chan & Elliot, 2004) and to examine the shifts in teachers' epistemological beliefs through participating in professional development program or attending teacher education courses (Brownlee et al., 2001; Walker et al., 2012). These studies had the domain-general approach to epistemological beliefs and concluded that there was a relationship between Western teachers' domain-general epistemological beliefs and conceptions of teaching-learning even though Chinese teachers represented a causal relationship between beliefs about the process of knowing and conceptions of teaching and learning (e.g., Chan & Elliot, 2004). Teachers' beliefs about nature of knowledge as complex and nature of learning as requiring effort (Sinatra & Kardash, 2004) were parallel to Buehl & Fives (2009)'s results about teachers' beliefs about sources and stability of knowledge and Braten and Ferguson (2015)'s findings of beliefs about sources of knowledge. They argued that teachers tended to explore new approaches based on the literature and their experiential resources.

Moreover, studies (Brownlee et al., 2011; Walker et al., 2012; Tanase & Wang, 2010) focused on exploring whether teachers' epistemological beliefs changed after long-term or short-term interventions. Their results indicated that teachers' domain-general beliefs were related to their beliefs about teaching and learning and translated into their practice (Tanase & Wang, 2010). Teachers held more sophisticated domain-general beliefs as they gained more experience, developed understanding, and engaged in reflections across years (Brownlee et al., 2011; Walker et al., 2012). Walker and colleagues (2012) and Brownlee and colleagues (2011) found that teachers could develop sophisticated beliefs about the structure of knowledge and speed of knowledge acquisition; but, they did not have improved beliefs about certainty and attainability of truth after the interventions. Furthermore, referring to the debates on domain-general and domain-specificity of epistemological beliefs, a few studies (e.g., Chai et al., 2006; Liu & Liu, 2011; Schommer-Aikins &

Duell, 2013) examined discipline-specific beliefs and how they were related to domain-general beliefs. Not many published studies examined teachers' domain-general epistemological beliefs and how they are translated into practices. The following section will discuss how the published literature addresses science teachers' epistemological beliefs regarding both domain-generality and domain-specificity of beliefs and how they are related to instructional practices.

Science Teachers' Epistemological Beliefs

Science education literature addressed teachers' epistemological beliefs referring to student-centered or teacher-centered approaches to teaching and learning as domain-specific beliefs. The results of empirical studies argued that science teachers' epistemological beliefs, teaching goals, and instructional practices were related to each other. A study by Kang and Wallace (2005) aimed to explore this relationship with three experienced high school teachers, who participated in a one-week summer workshop through analyzing teacher interview, classroom observations, and artifacts. They found that teachers' epistemological beliefs were closely connected to their instructional strategies to achieve their teaching goals. They revealed the alignment among teachers' beliefs, practices, and goals: Teachers, who viewed science as accumulative factual knowledge, aimed to transfer the knowledge and teach manipulative skills through structured laboratory activities. Teachers, who viewed science as tentative and evolving, aimed to challenge their alternative conceptions through integrating open-ended lab activities addressing multiple methods to enculturate students in the practices of scientists and to develop learners' conceptual understanding as well as scientific reasoning.

However, the alignment among teachers' goals, teaching actions, and epistemological beliefs was not the case for all teachers. Kang (2008) studied 23 pre-service science teachers from a science methods course through analyzing participants' learning histories, classroom observation,

lesson plans, video-recordings of teaching, and reflections on their practices. The study illustrated that teachers' goals were categorized into two: the development of scientific thinking skills (e.g., analytical thinking, curiosity, logical thinking) and the development of an appreciation of scientific knowledge (e.g., applying the scientific knowledge to everyday situations). Most teachers, who defined science as evolving theories and processes of multiple methods to answer scientific questions, aimed to encourage students for critical thinking, giving students opportunity to participate in group discussion, and sharing their ideas. On the other hand, teachers, who defined science as a body of knowledge as received facts, as constructed facts including the discovery of existing information or as received inquiry addressing the work of scientists, failed to enhance students' critical thinking. Instead, they aimed to develop an appreciation for scientific knowledge through integrating real-life applications of scientific concepts. Most participants' epistemological beliefs were reflected in their practices; but five teachers' practices were not representative of their beliefs due to lack of content knowledge, large class size, and passive students.

Science teachers' epistemological beliefs mediated whether they adopted the constructivist approach and whether they transferred their conceptions into their practices. Tsai (2008) indicated that teachers' scientific epistemological beliefs (SEBs) were aligned with teachers' classroom practices. For example, a teacher with positivist or traditional SEBs spent more time on lecturing or in-class examinations and situated students as passive learners, whereas teachers with constructivist SEBs integrated more student-centered activities and focused on students' prior knowledge and alternative conceptions. Teachers' in Mansour (2013) study demonstrated the similar consistency between their beliefs and practices. However, Mansour (2013) also found an inconsistency between in-service teachers' epistemological beliefs and practices reflected the social context of the classroom. Some teachers emphasized the

student-centered instruction, but teacher talk dominated their classroom implementation. This inconsistency between teachers' epistemological beliefs and practices was linked to the contextual factors. Management, school, and classroom-level factors such as administrative pressures, students' ability, time, resources, and subject matter knowledge influenced the transformation of teachers' beliefs into their practices.

Yang and colleagues (2008) explored in-service secondary 690 earth science teachers' views about the constructivist instruction and their epistemological beliefs. The data regarding teachers' views about constructivism were collected through a survey, and epistemological beliefs were explored through a Learning environment preference questionnaire analyzed through Perry's scheme. The results indicated that teachers considered constructivist instruction as advantageous to promote student participation in the learning activities and support knowledge construction, in-depth understanding of concepts, creativity, and motivation. However, some teachers had some concerns about the constructivist approach. Teachers, who disagreed with the constructivism, gave priority to meet the national curriculum standards rather than using alternative methods during instruction. Furthermore, participating teachers held either early multiplist or dualist epistemological beliefs, which were not consistent with the constructivist approach to science teaching. The study indicated that teachers did not hold sophisticated epistemological beliefs aligned with their views about the constructivist approach, which might be a reason for teachers' resistance to employing constructivist instruction.

Summary. The results from the studies reviewed in this section made the case to enhance supports for in-service and pre-service teachers to adopt new teaching methods to engage them in scientific practices and explicit reflection to develop sophisticated epistemological beliefs and improve their teaching practices. These studies used the term "epistemological beliefs" for

scientific epistemological beliefs without making a case for domain-specificity. Even though there was empirical evidence for the alignment between in-service teachers' epistemological beliefs, instructional strategies, and teaching goals (Kang & Wallace, 2005; Tsai, 2008), this alignment was not the case for all in-service and pre-service teachers due to personal factors such as beliefs about students' ability and subject matter knowledge as well as contextual factors such as administrative pressures, time and resources (Kang, 2008; Mansour, 2013). Moreover, Yang et al. (2008) reported that earth science teachers held constructivist approach to promote student participation in learning activities; but, holding naïve epistemological beliefs was the indicator of some teachers' traditional approach to science teaching due to their concerns about covering the content. These studies argued that prospective or in-service science teachers should be supported to experience authentic processes to construct their own knowledge and reflect on their ideas about educational practices or instructional approaches so that they can be encouraged to practice metacognition and rethink their epistemological beliefs.

Science teachers' beliefs about teaching and learning. Science teachers' traditional or constructivist beliefs about teaching and learning science may play a critical role in the lesson planning and classroom instruction. Recent reform efforts in science education suggest science teachers plan inquiry-based science lessons and promote and model the scientific inquiry, as well as the curiosity, openness to new ideas and data, skepticism as characteristics of science. However, there may be consistency or inconsistency between teachers' beliefs and practices; teachers' stated beliefs (espoused beliefs) may not be reflected in their instructional practices directly (enacted beliefs) due to internal factors (e.g. knowledge, social and cultural values) or external factors (e.g. curricular resources and administrative support) that might operate as mediators- filter, frames, or guides (Fives & Buehl, 2012, 2017).

Science teachers have essential roles in the implementation of new instructional strategies and curricular resources. Teachers' interpretation of the recommendations of reform and contextual factors may influence their beliefs about inquiry-based instruction (Smith & Southerland, 2007). Teachers may believe that inquiry-based instruction is a beneficial approach to science learning as a process rather than learning science as discrete facts to promote deep and independent thinking, exploration, creativity, active learning through observation, prediction, testing and drawing conclusions, develop their conceptual understanding, and enhance students' motivation towards learning science (Brown & Melear, 2007; Crawford, 2007; Rushton, Lotter, & Singer, 2011; Wallace & Kang, 2004).

However, teachers may have challenges in employing reform-based teaching approaches due to their beliefs about students, curriculum, and exam preparation. Teachers may believe that students do not have the ability to accomplish inquiry-based tasks or argumentation activities (Brown & Melear, 2007; Sampson & Blanchard, 2012; Wallace & Kang, 2004), and time required to implement inquiry tasks limit the time to cover the curriculum suggested by national standards (Herrington et al., 2011; Pimentel & McNeill, 2013; Wallace & Kang, 2004). Moreover, teachers may also have lack of knowledge and resources about inquiry-based instruction, lack of subject matter knowledge, less opportunity to collaborate with other science teachers, and concerns about preparing students for standardized tests that prevent their implementation of inquiry-based instruction (Crawford, 2007; Herrington et al., 2011; Levitt, 2001; Smith & Southerland, 2007).

Science teachers may need professional development support focusing on engaging students in authentic learning activities. Teachers' engagement in the design of inquiry-based tasks and reflection on the strengths and weaknesses of their experiences can improve their ability to promote inquiry-based instruction (Herrington et al., 2011). Teachers' participation into the development, implementation, and evaluation of new strategies and curriculum materials allows them to reconsider their role as a teacher

and how to support and enhance students' learning (van Driel et al., 2007). Teachers need opportunities to reflect on, share, and discuss their own experiences and receive feedback from other teachers about the implementation of reform-based instruction.

For example, Rushton and colleagues (2011) investigated the impact of a year-long professional development program on the beliefs and inquiry-based instructional practices of seven high school chemistry teachers using in-depth interviews and classroom observations. Teachers' learning of content-specific inquiry lessons, practicing teaching with high school students, and reflections on their enactment resulted in changes in their beliefs about teaching to employ inquiry-based strategies. Teachers had naïve conceptions about inquiry-based teaching before the professional development program. Professional development practices motivated teachers to try new instructional strategies through explicating their dissatisfaction with the current teaching practices and the need to engage students in guided hands-on activities. At the end of the program, teachers believed that inquiry-based instruction was a manageable and applicable to classroom instruction. Teachers considered Predict-Observe-Explain (POE) model as an effective strategy to enhance students' participation, make them think, conduct observations and experiments, and make scientific explanations. The study highlighted that the success of a professional development program might depend on the length, content, and format, as well as beliefs and abilities of the participating teachers, and teachers' professional development experiences may not always lead to changes in teacher practices parallel to reform suggestions.

Summary. Studies in this section focused on teachers' beliefs about teaching and learning science, particularly about inquiry-based instruction. Even though reform efforts suggested teachers to adopt the reform-based approach to science teaching and learning, teachers' lack of knowledge, resources, and collaboration opportunities about inquiry-based instruction as well as

their beliefs about students, curriculum, or exam preparation or contextual factors might serve as factors hindering the enactment. The empirical evidence from Rushton et al. (2011) emphasized the significance of training opportunities and development of new curriculum materials to support teacher learning about inquiry-based instruction that might help them develop positive beliefs about teaching and learning through inquiry-based instruction.

Science teachers' knowledge of nature of science. Nature of science (NOS) is a central goal of science education emphasized by many national (e.g., AAAS, 1993; NRC, 2007, 2012) and international documents (ACARA, 2013; OECD, 2012) and research (Abd-El-Khalick & Lederman, 2000; Wahbeh & Abd-El-Khalick, 2014; Erduran, 2014) to prepare scientifically literate individuals. These studies pointed out that teachers' understandings of NOS were an important factor to promote students' learning of the epistemological grounds of doing science—what science is and how scientific knowledge is developed. An area of research focusing on nature of science emphasized the influence of explicit and reflective approaches to NOS instruction to enhance learners' NOS understandings (McDonald, 2010). The explicit and reflective approach aimed to highlight the various aspects of NOS through understanding, experiencing, and reflecting these concepts during the hands-on or inquiry-based activities (Abd-El-Khalick & Akerson, 2004; Bell, Lederman, & Abd-El-Khalick, 2000). Some researchers also argued that integrating discussions and readings about historical and philosophical aspects of science in science methods courses might help to develop more profound and more coherent understandings of NOS (Abd-El-Khalick, 2005; Lin & Chen, 2002).

A study by Seung and colleagues (2009) investigated the changes in 10 middle-grade pre-service teachers' understandings of NOS as a result of explicit, not context-based, explicit, context-based, and explicit, case-based instructional approaches in a middle-grade science methods course.

Data collected through open-ended questionnaire, semi-structured interviews, and written artifacts. The results indicated that even though participants initially held naïve views about most aspects of NOS except the subjectivity and tentativeness, three approaches contributed to their understandings of NOS in different ways. Teachers developed more sophisticated views on the empirical and inferential nature of scientific knowledge through explicit-not context-based approach (e.g. Cube Activity), the role of creativity and imagination through explicit, context-based approach (e.g. Explicit, Context-based), and the understanding of the development of scientific knowledge and social and cultural influences in science through explicit, case-based approach (e.g. Reading and Developing a Case). Explicit, context and non-context based approaches were advantageous to combine science content, NOS, and inquiry-based activities during the instruction, whereas explicit-case based approach was more helpful to develop understandings of scientific knowledge. The results suggested that future studies should examine the relative contribution of each approach separately on enhancing teachers' knowledge of NOS.

In another study, McDonald (2010) examined the influence of integrating explicit NOS and argumentation instruction in both scientific and socio-scientific contexts on five secondary level pre-service teachers' knowledge of NOS in a science content course. Data collected through views of NOS questionnaire, science content surveys, interviews, classroom observations and discussions, and written artifacts. The results indicated that participants improved their views of NOS from naïve or limited views to partially informed or informed views. Variety of factors mediated the teachers' views of NOS including contextual, task-specific, and personal factors. The study suggested that teachers could easily learn the aspects of NOS through socio-scientific contexts rather than scientific contexts, and integrating various activities such as argumentation scaffolds, epistemological probes, and alternative explanations promoted the development of NOS

conceptions. The author argued that generating disequilibrium about the inadequacy of teachers' NOS conceptions might help them look for alternative and more informed views of NOS. The study provided empirical evidence for the implementation of NOS and argumentation instruction as sufficient to support pre-service teachers. The author suggested that further research should examine whether these teachers will retain their knowledge of NOS and be able to translate their understandings of science into classroom instruction.

Studies also explored the influence of professional development programs or experiences focusing on NOS instruction to enhance teachers' understandings of science. In Akerson, Cullen, and Hanson (2009)'s study, the authors worked with four practicing elementary science teachers, who attended a two-week summer professional development program focusing on NOS and inquiry. Data collected through teaching artifacts and pre-, post-, and delayed post- (three months after the program) Views of NOS and Scientific Inquiry questionnaires with follow-up interviews. The results indicated that teachers had developed their NOS understandings by the end of the summer workshop program, in which teachers engaged in the use of inquiry-based learning cycle in the design and modification of the lessons and experienced the scientific practices such as using the models and communicating the design and analysis of scientific investigation. However, practicing teachers did not address the aspects of NOS during the science instruction after the professional development program, and they lost their gained knowledge of NOS three months after the program. The results of the study were consistent with Akerson et al. (2006), which linked pre-service elementary teachers' NOS understandings to their domain-general epistemological beliefs addressing Perry's scheme. The study indicated that a few teachers with sophisticated epistemological beliefs used metacognitive strategies to reflect on their NOS understandings, and they could retain their improved knowledge of

NOS, whereas the majority of teachers with naïve epistemological beliefs regressed their conceptions.

In another study, Morrison, Raab, and Ingram (2009) explored how professional development experience in a research setting would influence elementary, middle, and secondary level teachers' knowledge of NOS. Twenty science teachers attended a two-week professional development program in a research center and engaged in the variety of activities including shadowing scientists' work, interviewing and discussing with scientists about their NOS understandings, science concepts, and conceptions about teaching and learning science. Data collected through pre- and post- views of NOS questionnaire, informal interviews, reports about the work of scientists, lesson plans, class discussions, and reflections on the research experience. The results indicated that teachers' experiences in research facility helped them shift their inadequate views to adequate knowledge of NOS by the end of the two-week experience. Secondary science teachers received higher scores in the initial questionnaire, and their scores did not change significantly because they had undergraduate degrees in science that helped them develop prior experiences in the science laboratories through working with scientists. However, elementary and middle school teachers did not hold a science degree, and they had lower scores than secondary science teachers; research experiences such as interviewing, job shadowing, and informal conversations resulted in changes in their knowledge of NOS. The study suggested that teachers from elementary, middle and high schools experienced changes in their knowledge of NOS based on their prior experiences. Teachers' interactions with scientists were helpful to develop their NOS understandings, and they did not have to be involved in a full research project or attend a science methods course to strengthen their knowledge of NOS.

Posnanski (2010) examined the impact of a two-year professional development program on 22 in-service elementary teachers' NOS understandings. The PD program included weeklong summer institutes (seven hours five days) and school year course sessions (three hours per night, five nights per fall and spring semesters). Participants were introduced to the seven aspects of NOS through explicit activities, readings, and journal reflections. The program also included modeling of effective science instruction, questioning strategies, productive classroom conversations, cooperative learning techniques, and science research activities. Data collected through pre- and post-program nature of science surveys, program evaluation surveys, interviews, and action research plan documents. The analysis of the data through statistical procedures and reduction techniques indicated that 18 of 22 participants had positive changes from pre- to post- project NOS surveys in NOS views. Four teachers had unchanged and high scores for NOS views. The teachers started the program with more naïve views and ended the program with more informed views. These teachers' scores were higher for empirical-embeddedness, human endeavor, tentativeness, and social and cultural aspects of NOS than the difference between observation and inference and theory and law aspects. The study indicated that the teachers' participation in an activity-based environment including journal readings, scientific research techniques, and inquiry-based instruction had a significant impact on developing NOS views.

A study by Donnelly and Argyle (2011) investigated the change in 36 elementary, middle, and high school teachers' nature of science views through participating in a physical science professional development graduate course. Participants attended five days summer workshop and eight monthly follow-up sessions throughout the academic year. During the summer meeting and follow-up meetings, the teachers engaged in several decontextualized (such as Tricky Tracks, Mystery Tubes, the Cubes) and contextualized (such as theory/law activity,

mystery electric circuits, discussion of the history of science) activities. Data collected through pre- and post-PD views of nature of science questionnaire and teacher reflections collected after the PD program, during the follow-up meetings, and at the end of the course. The results indicated that participants held adequate views of the empirical, tentative, and creativity aspects of NOS even before the PD program. Professional development program helped the teachers improve their understandings of tentativeness, the distinction between theory and laws, the role of indirect evidence, creativity, and subjectivity aspects. The teachers' learning gains were statistically significant for only the distinction between theory and laws and the role of indirect evidence aspects. The study illustrated the effectiveness of the PD program through emphasizing the NOS instruction across all grade levels, integrating both decontextualized and contextualized NOS instruction, and modeling the engagement in NOS activities.

Teachers' engagement in a set of activities with explicit-reflective approach also helped them develop substantial gains in the conceptions of nature of science (Akerson et al., 2000). Integrating conceptual change approach to NOS instruction has been utilized as a theoretical framework to support teachers in developing adequate knowledge of NOS through challenging their existing ideas and engaging them in explicit reflection (Abd-El-Khalick & Akerson, 2004). In a more recent study, Bell, Mulvey, and Maeng (2016) examined the change in 70 pre-service secondary science teachers' NOS conceptions as they attended two secondary science methods courses including a continuum (from non-contextualized, to minimally, moderately, and highly contextualized activities; such as science content to scientific inquiry) consistent with conceptual change theory. The authors defined the conceptual change approach as creating a conceptual conflict in learners' prior conceptions towards developing more scientific conceptions through discussion and reflection. Data collected through views of NOS questionnaire and post-instruction

interviews. The results indicated that participants' conceptions substantially improved from non-aligned to partially or fully aligned through NOS instruction in different contextualization. By referring to the results from a prior study, Bell et al. (2011), the authors argued that the degree of contextualization while teaching the science content did not influence teachers' NOS conceptions; instead, they suggested that explicit and reflective instruction might result in a substantial development in participants' knowledge of NOS.

Mulvey and Bell (2017) examined 25 in-service middle-school teachers' retention of NOS conceptions after participating a 46-hour graduate-level professional development course focusing on explicit and reflective NOS instruction and inquiry along with a similar continuum as mentioned in Bell et al. (2016). Data collected through views of NOS questionnaire and follow-up interviews at the beginning and end of the professional development program and 10-months after the program. The results indicated that NOS instruction along a continuum helped teachers participate in discussions in varied contexts and develop informed understandings of NOS by the end of a short professional development program. Participants' responses to the questionnaire and interviews also revealed that they retained their improved understandings of NOS 10 months after the program. These studies (Bell et al., 2016; Mulvey & Bell, 2017) supported pre- and in-service science teachers' development of NOS understandings through mixed contextualization approach to NOS instruction that linked the abstract NOS conceptions to activities addressing science practices.

In a recent study, Mesci and Schwartz (2017) examined preservice teachers' changes in NOS views and reasons of changes in their nature of science conceptions. The study had a conceptual change perspective from Posner et al. (1982). Participants were 14 undergraduate students from science, elementary education, and secondary science majors from a science

methods course targeting NOS aspects. The course aimed to support students to have an authentic science learning experience, to translate their knowledge of NOS into practice, and to guide them in their teaching practice. Data collected through pre- and post-questionnaires, semi-structured interviews, observation field notes, and student-created artifacts. The results indicated that most student teachers possessed naïve views about most aspects of NOS. By the end of the semester, almost all students improved their understandings about multiple scientific methods, subjectivity, creativity, observation and inferences, and empirical embeddedness. Student teachers had difficulty to change aspects of tentativeness, the difference between theory and law, and sociocultural embeddedness. The study also explicated the factors influencing the development of views of NOS as instructional, motivational, and sociocultural factors as related to students' NOS views. Instructional factors included hands-on activities, journal articles and chapters, classroom discussions, and feedback. Motivational factors were divided into two as personal and social factors. Personal factors included intrinsic task motivation, performance motivation, utility value, competence belief, and self-efficacy. Social factors included peer support, teamwork, and work in a real science research lab. Participants' background and possible worldview differences were also influential as sociocultural factors. The study had further implications to inform the barriers and scaffolds of NOS instruction to change science teachers' NOS views.

Teachers' adequate understandings of NOS may or may not be sufficient to employ their knowledge into practice- to design lessons or instructional sequences addressing aspects of NOS and integrate these into the instruction. Previous studies (Abd-El-Khalick, Bell, & Lederman, 1998; Bell et al., 2000; Brickhouse, 1990; Lederman, 1999) found that science teachers were not successful in translating their knowledge of NOS into their practices even though they had informed understandings of science. Differences were observed between experienced and

inexperienced or pre-service teachers indicating that experienced science teachers' practices were consistent with their knowledge of NOS (Brickhouse, 1990; Lederman, 1999), whereas pre-service or inexperienced teachers' practices were inconsistent due to their concerns about NOS instruction (Abd-El-Khalick et al., 1998; Bell et al., 2000; Lederman, 1999).

In a more recent study, Capps and Crawford (2013) examined the influence of an intensive weeklong summer program on teachers' knowledge of inquiry and NOS and practices. Twenty-six 5th to 9th grade experienced teachers' prior conceptions of NOS and inquiry were assessed through open-ended questionnaires targeting their views about inquiry and NOS, and prior practices were also described through observations of classroom instruction. The results indicated that well-qualified teachers did not hold informed prior conceptions about NOS and inquiry, and they were not able to address the aspects of inquiry and NOS in their classroom practices explicitly. However, participating in an intensive weeklong summer program helped these teachers develop informed knowledge of inquiry and NOS, which they could translate their knowledge into classroom practices after the summer program. The findings emphasized the linear relationship between teachers' views of inquiry and NOS and their practices. The study suggested that the professional development programs should focus on addressing the development of teachers' knowledge of inquiry and NOS to employ these practices in the classroom successfully.

However, Herman, Clough, and Olson (2013) argued that there was not always a linear relationship between teachers' knowledge of NOS and practices, and translation of their knowledge of NOS did not depend on their teaching experience. The authors examined the impact of NOS instruction on teachers' practices after graduating from the same extensive secondary science education program. The data collected from 13 secondary science teachers

with 2 to 14 years of teaching experience through classroom observations, instructional artifacts, and “Student Understanding of Science and Scientific Inquiry (SUSSI)” questionnaire. Their results indicated that experience was not an essential factor in NOS instruction. Teachers held informed or transitional NOS understandings, and even though teachers held informed knowledge of NOS, they were categorized as middle or low implementers of NOS. Participating teachers’ knowledge of NOS were more informed than what they translated into their practices or lesson artifacts. The authors argued that teachers’ successful NOS instruction might be related to linking NOS teaching with teaching through different methods or approaches such as inquiry activities or integrating history or philosophy of science approaches to address the aspects of science. The study suggested that teachers need to develop knowledge of NOS along with knowledge of subject matter and inquiry-based instruction to efficiently teach NOS in different contexts.

In another study, Wahbeh and Abd-El-Khalick (2014) examined how an integrated NOS instructional intervention had an impact on science teachers’ knowledge of NOS and their instructional planning and practices. Participants were 19 middle and high-school teachers attended six-week 36-hour NOS focused professional development summer course with explicit-reflective, metacognitive, content-embedded approach within a conceptual change framework. Data collected through pre-, post-, and delayed-post (five months after the intervention) views of NOS questionnaires with follow-up semi-structured interviews, classroom observations, teacher artifacts including reflection papers and logs. The results of the study indicated that most participants held naïve knowledge of many aspects of NOS. A few participants appreciated the role of evidence and social and cultural values in science. After the intervention, most of the teachers developed informed or partially informed views on those aspects even though they still

held naïve conceptions on the relationship between theory and laws and the scientific method. Delayed-test results taken five months after the intervention demonstrated that teachers' knowledge of NOS retained; only a few (13%) shifts occurred on teachers' conceptions from partially informed to informed views on inferential aspect of science and scientific method and from informed to partially informed views on theory-laden, tentativeness, creativity, and social and cultural aspects of science. In parallel to teachers' knowledge of NOS, teachers were successful in addressing some aspects of nature of science including empirical, inferential, tentative, and social and cultural aspects of NOS in the instructional planning and during the classroom instruction through discussions even though they had a teacher-centered approach for science instruction. The study concluded that teachers' knowledge of NOS was an important factor to transfer their knowledge into practice; but interacted with facilitating or hindering factors such as content knowledge, knowledge of students' conceptions for NOS, expertise in inquiry-based teaching, and lack of resources.

Summary. The studies above demonstrated the significance of explicit-reflective approach to NOS instruction to develop teachers' understandings of science to combine science content, NOS, and inquiry-based instruction as well as to develop understandings of scientific knowledge (Bell et al., 2016; Seung et al., 2009). Teachers could develop knowledge of NOS through integrating NOS instruction into socioscientific contexts or through using activities with the explicit-contextual approach (Bell et al., 2016; McDonald, 2010). However, Bell and colleagues (2016) argued that the level of the contextualization did not influence teachers' NOS understandings; instead, the explicit and reflective approach was more effective to improve teachers' knowledge of NOS.

Studies also focused on exploring whether changes occurred in science teachers' knowledge of NOS after attending science methods courses or professional development

programs. For example, the changes in teachers' knowledge of NOS were related to their prior knowledge and experiences. Elementary and middle school teachers experienced higher positive shift than secondary school teachers due to their lack of science context background (Morrison et al., 2009). These studies indicated that pre-service and in-service teachers' NOS conceptions improved after attending a science methods course or a professional development program, but whether these conceptions retained after the program was a question. Akerson and colleagues (2009) found that elementary science teachers did not retain their informed NOS conceptions three months after two-week professional development program. They supported their previous findings from Akerson, Morrison, and McDuffie (2006), which linked the retention of teachers' NOS understandings to their sophisticated epistemological beliefs. In Posnanski (2010) and Donnelly and Argyle (2011)'s studies, the teachers had adequate and unchanged understandings at the beginning, or they developed more informed views by the end of the study. Posnanski (2010) found that in-service elementary teachers' naïve understandings of NOS aspects became more informed by the end of the PD program even though four teachers had informed and unchanged views from the beginning of the study. Participants had higher scores on empirical, human endeavor, tentativeness, sociocultural aspects of NOS throughout the study.

In Donnelly and Argle (2011)'s study, the teachers had adequate views of empirical, tentativeness, and creativity aspects of science at the beginning of the study, and they improved their views on the tentativeness, the distinction between theory and laws, the role of indirect evidence, creativity, and subjectivity aspects. A more recent study with conceptual change approach, Bell et al. (2016), indicated that pre-service secondary science teachers' NOS understandings retained ten months after a week-long professional development program. Mesci and Schwartz (2017) found that pre-service teachers could develop the most aspects of NOS

views through science methods course, but they had difficulty in tentativeness, the difference between theory and law, and sociocultural values. The study also revealed the factors influencing the development of views of NOS as instructional, motivational, and sociocultural factors. These studies suggested that further research should focus on exploring whether teachers' knowledge of NOS retained after a period focusing on NOS instruction with different teacher groups and in varied contexts with different methodologies, particularly, conceptual change theory.

Additionally, the results of studies, which explored whether teachers' knowledge of NOS was translated into practice, indicated that teachers' NOS understandings might not be necessarily generated during the instruction. Even though Capps and Crawford (2013) argued that there was a linear relationship between teachers' knowledge of NOS and NOS instruction, Herman et al. (2013) and Wahbeh and Abd-El-Khalick (2014) found the inconsistency between teachers' knowledge of NOS and what they translated into practices. Teachers' NOS instruction was not related to teaching experience (Herman et al., 2013); and there might be mediating factors such as teachers' content knowledge and knowledge of student conceptions for the translation of NOS conceptions (Wahbeh & Abd-El-Khalick, 2014). These studies pointed out the need for further studies to support teachers' development in NOS instruction through designing professional development experience targeting enhancing teachers' NOS understandings along with knowledge of reform-based instruction and science content to successfully translate their knowledge into practice.

Conclusions

This chapter provides a theoretical background for the current study that aims to explore the influence of a one-year professional development program on urban science teachers' PCK of argumentation and epistemological beliefs. The study is also interested in examining whether

teachers may translate their PCK of argumentation and epistemological beliefs into science instruction and mediating factors of the argumentation instruction. The review of 25 articles published in peer-reviewed journals addresses teachers' role in creating a classroom culture that may promote students' participation into science learning through argumentation with the appropriate level of complexity and scaffolding (Berland & McNeill, 2010). These studies highlight that teachers need to be aware of the complexity of the classroom context including the implicit social and epistemological norms (Pimentel & McNeill, 2013). In other words, teachers need to move away from the "pseudo argumentation," which encourage students to focus on merely the use the structural aspect of arguments and disregard the development of social and epistemic understandings of argumentation- how claims are constructed, debated, and critiqued in science (Berland & Hammer, 2012).

The results of the reviewed studies suggest that further research should focus on how teachers adopt new instructional resources, strategies, or models, what supports they need for enacting the existing resources with fidelity, and how they translate their understanding of new methods into practice (Choi et al., 2015; McNeill & Krajcik, 2008; Sadler, 2006; Sampson et al., 2011). They report that for effective teaching, science teachers need to develop both content knowledge and pedagogy to promote student-centered instruction around argumentation. They may need to model how to justify their claims and critique alternative arguments using appropriate evidence and reasoning in a small group or whole class discussions (Choi et al., 2015; Pimentel & McNeill, 2013; Simon et al., 2006). They may also support students' learning of academic language through promoting construction, critique, and communication of arguments during writing and discussion activities across scientific and socio-scientific contexts (Christodoulou & Osborne, 2013; Pimentel & McNeill, 2013; Swanson et al., 2014). For

example, Sampson and colleagues develop Argument-Driven Inquiry (ADI) model, and their research provides empirical evidence for the effectiveness of ADI investigations on enhancing students' participation, conceptual understanding, writing skills, and engagement in oral argumentation. However, the authors suggest that future research should examine how a teacher may interpret and implement an instructional model in a unique way, which may result in different learning outcomes.

Moreover, the results of these studies indicate that teachers need to develop more sophisticated PCK of argumentation including knowledge of student challenges and instructional strategies to effectively incorporate argumentation into science instruction. They suggest the design of professional development programs, science methods courses, and educative curriculum materials support both in-service and pre-service teachers' learning around argumentation instruction (Beyer, 2009; Christodoulou & Osborne, 2013; Sampson & Blanchard, 2012). These professional supports aim to establish a foundation for teacher learning through problematizing and reflecting on their existing practices and previous experiences while adopting this complex scientific practice to support diverse student learning (McNeill, 2009; McNeill et al., 2017; Simon et al., 2006). Previous studies argue that teacher learning opportunities should be longitudinal and continuous (Erduran et al., 2015; Zembal-Saul, 2009) that teachers need sufficient time to examine and enact new ideas from the professional development program and curricular suggestions in different contexts (Beyer & Davis, 2009; Knight-Bardsley et al., 2016; Marco-Bujosa et al., 2016), to reflect on their experiences through collaborating with other teachers, and to translate their knowledge into practice (Knight-Bardsley et al., 2016; Marco-Bujosa et al., 2017). These studies also examine the factors that may mediate the argumentation instruction including contextual and personal factors (Marco-Bujosa et al.,

2017; McNeill et al., 2017), and they recommend that further research should explore the other possible factors that might facilitate or hinder the implementation of argumentation.

However, teachers' beliefs may serve as barriers to how they use these educative resources or instructional models focusing on argumentation (McNeill, 2009). The researchers recommend that future studies should focus on examining how teachers' beliefs and knowledge play a role in teachers' implementation of argumentation (McNeill, 2009; McNeill, Pimentel, Strauss, 2013) as well as the relationships among the professional support, teacher beliefs, and classroom practice (Crippen, 2012). Teacher beliefs are part of a larger belief system consisting of epistemological beliefs that may have a mediating role in how teachers value and promote the scientific argumentation as well as how they acknowledge the tentative nature of knowledge while incorporating argumentation instruction (Liu & Roehrig, 2017). Examining teachers' epistemological beliefs may help researchers understand how their domain-general and domain-specific beliefs develop teachers' PCK of argumentation as well as whether or not teachers translate their epistemological beliefs into practice.

This chapter also reviews the published literature focusing on teachers' epistemological beliefs including both domain-general and domain-specific beliefs. The review of 11 articles from peer-reviewed journals focuses on teachers' domain-general epistemological beliefs addressing teachers' beliefs about specific dimensions such as beliefs about the speed of knowledge acquisition, the source of knowledge, or knowledge construction and modification. These studies refer to teachers' domain-general epistemological beliefs with different purposes: to examine the relationship between specific dimensions of epistemological beliefs and conceptions of teaching and learning (e.g. Buehl & Fives, 2009; Braten & Ferguson, 2015; Chan & Elliot, 2004), to investigate the shifts in teachers' epistemological beliefs through participating

in professional development programs or attending teacher education courses (Brownlee et al., 2001; Walker et al., 2012), and to explore the alignment between teachers' domain-general epistemological beliefs and instructional practices in parallel to shifts in their epistemological beliefs (Tanase & Wang, 2010). Addressing the debates on domain-general and domain-specificity of beliefs, a few studies (e.g., Chai et al., 2006; Liu & Liu, 2011; Schommer-Aikins & Duell, 2013) examine discipline-specific beliefs and how they are related to domain-general beliefs. These studies suggest that future research should focus on exploring how specific dimensions of both in-service and pre-service teachers' epistemological beliefs change from naïve to sophisticated level to promote meaningful learning and to help teachers develop reflective thinking about existing practices (Buehl & Fives, 2009; Cheng et al., 2009; Walker et al., 2012). The researchers are also interested in the relationship among teaching experience, epistemological beliefs (the relationship between domain-general and domain-specific epistemological beliefs), and instructional practices as well as other teacher characteristics such as motivation, study approaches, age, and gender (Braten & Ferguson, 2015; Chai et al., 2006).

Additionally, the review of 25 articles examines science teachers' epistemological beliefs in general as well as domain-specific beliefs involving teachers' beliefs about teaching and learning science and their knowledge of NOS. Studies on science teachers' domain-specific epistemological beliefs (e.g., Kang & Wallace, 2005; Tsai, 2008; Crawford, 2007; Morrison et al., 2009) make recommendations for further implementations. For example, they think both in-service and pre-service teachers should be aware of and reflect on their existing beliefs and teaching experiences to reform more sophisticated epistemological beliefs and translate their beliefs into practice (Kang & Wallace, 2005; Kang, 2008; Mansour, 2013; Smith & Southerland, 2007). They also suggest that further research should explore the factors that help teachers

develop sophisticated beliefs (Brown & Melear, 2007)- why some teachers evaluate students' conceptions in different ways and set different instructional goals (Kang & Wallace, 2005). They are also interested in investigating the interplay between teachers' domain-specific epistemological beliefs and students' learning (Yang et al., 2008; Tsai, 2008) as well as to determine the profiles for the relationship between scientific epistemological beliefs and beliefs about teaching and learning in general (Belo et al., 2011).

Furthermore, studies focusing on teachers' knowledge of NOS reach contradictory conclusions that teachers' knowledge of NOS may or may not translate into their practices (Capps & Crawford, 2013; Herman et al., 2014). The results of these studies suggest that supporting teacher learning through professional development programs focusing on both scientific inquiry and nature of science may help teachers translate their knowledge of NOS into practice (Akerson et al., 2009; Capps & Crawford, 2013). They are also interested in exploring how teachers facilitate the NOS and argumentation instruction in a different context with diverse groups (McDonald, 2010) and whether or not teachers' knowledge of NOS retains a period after the intervention (Bell et al., 2016; Mulvey & Bell, 2017). Posnanski (2010) and Donnelly and Argle (2011) investigated the change of in-service science teachers' NOS views and found that in-service teachers either had adequate NOS understandings or improved their naïve views towards more informed understandings by the end of the study. Mesci and Schwartz (2017) explained the factors influencing the development of views of NOS as instructional, motivational, and sociocultural factors. These studies recommend the design of intensive and long-term professional support and science methods courses to encourage in-service or pre-service teachers to reflect on their NOS understandings or use metacognitive strategies about NOS for the development and retention of their conceptions (Akerson et al., 2006). The

professional development programs should support teachers in the enactment of explicit-reflective approach to NOS instruction through integrating historical stories about science and mixed contextualized activities focusing on either the science content or scientific argumentation to examine the relative contribution of different contexts on teachers' knowledge of NOS as well as on students' learning (Seung et al., 2009; Herman et al., 2013).

These studies highlight that future research should explore teachers' PCK of argumentation and epistemological beliefs with larger sample size and with a variety of methods such as interviews, observations, concept mapping or think-aloud protocols to understand how knowledge and epistemological beliefs develop and translate into practice in different disciplines and contexts. They suggest a specific focus on understanding the factors influencing teachers' low-quality PCK of argumentation and naive epistemological beliefs to help them develop more sophisticated epistemological beliefs, understand their students' epistemological beliefs and learning difficulties, and to design lesson plans, curriculum materials, and professional development programs accordingly.

Summary of the Chapter

Science teachers' PCK of argumentation including knowledge of student conceptions and instructional strategies for both structural elements of an argument and the dialogic process may or may not directly be translated into their lesson planning and teaching practice. Teachers' epistemological beliefs (both domain-general and domain-specific beliefs) and other factors such as students' ability, policy, or administration may mediate both teacher learning of argumentation and the translation of their PCK of argumentation into classroom practice. This study assumes that teacher professional knowledge is complex and dynamic and informed by epistemological beliefs and other factors. This complexity of science teaching and learning suggests the further research to focus on understanding the relationship between teacher knowledge, epistemological beliefs, and

practice. Therefore, this study intends to address a gap in the literature about science teachers' PCK of argumentation, epistemological beliefs, and practices in a single study. The study aims to examine the influence of one-year professional development program around the implementation of argumentation instructional model, Argument-Driven Inquiry (ADI), on urban science teachers' PCK of argumentation and epistemological beliefs, whether teachers translate their PCK of argumentation and epistemological beliefs into practice, and what mediating, facilitating and hindering factors, influence teachers' practices.

CHAPTER III

METHODOLOGY

According to Schwandt (2007), methodology is “a particular social scientific discourse (a way of acting, thinking, and speaking) that occupies a middle ground between discussions of method and discussions of issues in the philosophy of social science” (p. 193). This chapter explains the approach to scientific inquiry of the present study that specifies the choice of research questions, the assumptions, the research design to investigate the problems of interest, the methods of sampling, data collection and analysis, and the criteria of quality to develop the logical link between the problem, data collection and analysis strategies, and the interpretation of the findings (Crotty, 1998; Schwandt, 2007; Teddlie & Tashakkori, 2009). The following sections present the purpose of the study, the rationale of the research design, and how the design of the study facilitated the procedures to select participants and to choose the appropriate methods of data collection and analysis and the ethical considerations to investigate the research questions.

Research Design

The research used a qualitative case study design to address the urban science teachers’ epistemological beliefs, PCK of argumentation, and implementation of argumentation in science classrooms. The study aimed to explore how epistemological beliefs and PCK of argumentation relates to the implementation of argumentation; as well as to understand any changes in science teachers’ epistemological beliefs and PCK of argumentation through one-year intensive professional development focusing on argumentation instruction. The study also explored the other factors that may mediate the argumentation instruction. The research questions guiding the present investigation are:

1. How does the participation in one-year PD program influence PCK of argumentation and epistemological beliefs?
2. How are the teachers' PCK of argumentation and epistemological beliefs reflected in their practice?
3. What other factors do the teachers report as mediating the argumentation instruction?

Qualitative research strategies guiding this study aim to explore deep and detailed analysis of the influence of a professional development program on in-service science teachers' PCK of argumentation, epistemological beliefs, and argumentation instruction. Merriam (2010) suggested that qualitative research starts with assumptions, worldview and the use of a theoretical lens that refer to the meaning participants bring to a social problem. Researchers gather multiple forms of data including interviews, observations, and documents by empowering people to share their stories, observing them in their natural settings or examining the artifacts. According to Bogdan and Biklen (2007), "design is used in research to refer to the researcher's plan of how to proceed," (p.54), suggesting that the process is emergent; after entering the field, the research questions, the forms of data collection, and the research setting may be modified. The process is also inductive; researchers use pieces of information from different resources, interviews, and observations, to build concepts, categories or theories.

One approach to qualitative research is "case study," in which the researcher examines a bounded system or multiple bounded systems (cases) in their natural contexts through multiple sources of information without involving explicit control or manipulation of variables. Merriam (2009) describes the qualitative case study as "an in-depth description and analysis of a bounded system." Qualitative case studies differ from other qualitative research approaches, ethnography, phenomenology and narrative through "the unit of analysis." The primary characteristic of case

study research is to determine the object of the research as well as the product of inquiry as the case, rather than the topic of investigation, which is a bounded system, a single entity or a unit. The case would be a single individual, group, event or multiple cases defined for their unique properties that make them different from other cases. A case study can also be categorized as embedded if there are subunits within a case, but categorized as holistic if there is no subunits identified (Yin, 2014). This study has a multiple holistic case design that includes two or more cases from different contexts; but share a common characteristic or are categorically bound together.

Participants and settings

Teddlie and Tashakkori (2009) define purposeful sampling as a dominant strategy in educational research in which “particular settings, persons, or events were deliberately selected for the important information they could provide that could not be gotten as well from the other choices” (p. 170). The sample selection criteria are informed by the purpose of the inquiry, its theoretical orientation or gaps in knowledge about the study population. The method of sample selection in the present study follows the purposeful sampling technique to recruit the participants for a yearlong study through convenience sampling that provides the selection of the most readily available participants. As Ritchie and colleagues (2013) suggest, the locations are usually chosen due to their salience to the subject matter under inquiry such as implementation of argumentation in high school classrooms. The sampling strategy in this study is convenient because the research sites are selected from a large urban school district in the southeastern region of the United States, where the school district has adopted an argumentation instructional model in science classrooms, and the researcher attends the university and spends most of her time during the study. It is a convenience sampling since the participants are selected by professional contacts with the district K-12 science coordinators, science coaches, and

educational professionals who work closely with the urban science teachers from primary science disciplines including biology, chemistry, physics or physical science, and earth systems.

The convenience sampling has limitations due to the selection of the most appropriate cases for the study, and the generalizability of the results is problematic and constrained based on the small sample size and the nature of selection bias. The selection process includes proximity to the research site, professional contacts, and the urban science teachers' agreement to participate in the extensive data collection. Therefore, the sample is selected in a simple way for the researcher. The robust generalizations for a larger population are not possible; the results represent the change in the science teachers' epistemological beliefs and PCK of argumentation, how these constructs are translated into the argumentation instruction, and what other factors influence the implementation of argumentation instructional model. The results address the preparation of the pre-service and in-service teachers' professional development and teacher education programs.

These science teachers are selected from a large urban school district located at the center of the southeastern region of the United States. There are 106 campuses with 91 Title I schools, including 12 middle schools and 18 high schools, as well as two single gender campuses and two adult education programs. According to 2016 - 2017 demographic information, the urban school district serves approximately 52,000 students. The demographics of the student population involve 74.9% African-American, 15.1% Caucasian, 6.87 % Hispanic, 1.85% Multiracial, and 1.28% other (Asian, American Indian, Pacific Islander and other) ethnic distribution. Within that population, nearly 77% of the student population is eligible to receive free and reduced-priced meals. The school district provides various science courses at the high school level, including honors and general levels as well as AP and IB versions of the courses for biology, chemistry, earth systems, physical science,

physics, and environmental science. The participants of this study are from several science disciplines across the district schools.

The urban school district encourages the science teachers to adopt instructional strategies that can promote students' engagement in scientific practices, particularly argumentation in middle and high school science classrooms. Through professional relationships with district science coordinators as well as district science coaches, 12 science teachers participated in a professional development (PD) in June 2016 on the implementation of an instructional model designed for argumentation instruction called Argument-Driven Inquiry (ADI) (Sampson et al., 2011). Detailed description of the instructional model is provided in Appendix A. PD program in June 2016 lasted five days approximately 30 hours; these teachers had opportunities to reflect on their knowledge, beliefs, and practices after the PD program. Twelve science teachers had completed surveys and questionnaires regarding their PCK of argumentation and knowledge of NOS at the beginning and end of the PD program, and they also wrote reflections on their learning experiences about argumentation and nature of science each day during the PD program in summer. Then, the teachers participated in a follow-up meeting in the middle of the Fall semester after the PD program to discuss the strengths and challenges in the enactment of the instructional model, share and analyze their students' artifacts and their lesson plans from the implementation of ADI model. By the end of the year, they completed the surveys and questionnaires regarding the PCK of argumentation, domain-general epistemological beliefs, and knowledge of NOS at the end of the study. They also participated in a semi-structured interview to reflect on their PCK of argumentation, epistemological beliefs, and experiences of ADI implementation. The detailed description of the PD program is provided in Appendix B.

The current study presents the results from four urban science teachers as cases, who are selected among twelve teachers from the PD program. Twelve teachers are asked for their voluntary participation for extensive data collection, which includes field notes from classroom observations, these teachers' written journals or informal conversations about the implementation of argumentation or epistemological beliefs between March and May 2017, and a semi-structured interview at the end of the study. The data collected after the PD program focuses on exploring whether or not the science teachers translate their epistemological beliefs and PCK of argumentation into classroom practice, how explicit argumentation instruction influences the science teachers' PCK of argumentation and epistemological beliefs, and the other factors mediating the argumentation instruction. The four teachers who agreed to participate in the extensive data collection were the unit of analysis. After completing the preliminary agreements with four science teachers to participate in this aspect of the study, the permissions from the school principals were taken to be able to access four teachers' classrooms to conduct research. The initial data sources, which were collected during the PD meetings, were included as the data sources of this study. The school and demographic information of the participating teachers were presented on Table 6 and Table 7 respectively.

Table 6

The school information of participating teachers (N= 4)

Teacher	Type of School	Grade of Students	Free-Reduced Lunch Status
Eva	Title-1	8 th	99%
Asia	Title-1	9-10-11-12	100%
Bella	Title-1	10 th	100%
Olivia	Title-1	12 th	80+%

Table 7

The teacher demographic information (N= 4)

Teacher	Major	Highest Level of Education	Years of Teaching Experiences	Classes Taught ²
Asia	Psychology	Bachelor's	16	Literature, Math, <u>Physics,</u> <u>Chemistry, Biology,</u> <u>Environmental Science,</u> <u>Forensic Science</u>
Bella	Psychology	Bachelor's	5	<u>Physical Science,</u> Physics, Scientific Research, AP Psychology
Eva	Biology	Master in secondary Science/ Specialist for Educational Leadership	26	Biology, Chemistry, Physics, <u>Physical Science,</u> Environmental Science, Forensic Science
Olivia	Biology, Sociology, Psychology	Master's	5	Physics, Physical Science, <u>Anatomy</u>

Data Collection

Qualitative case study design involves the collection of multiple data sources in a single study, and triangulation strategies emphasize the significance of combining data sources to enhance the reliability of findings (Teddle & Tashakkori, 2009). This intended study utilized qualitative data sources, which were supported through surveys and assessment instruments from the published literature. Quantitative data sources included the PCK of argumentation assessment (McNeill et al., 2016), the Views of Nature of Science-270 (VNOS-270) questionnaire (Schwartz, 2007), and the Epistemological Beliefs Survey (EBS) (Wood & Kardash, 2002) to assess teachers' PCK of argumentation, domain-specific epistemological beliefs, and domain-general epistemological beliefs respectively and support the qualitative data sources.

² The classes that the researcher observed were bolded and underlined

Qualitative data sources included the collection of the artifacts that four teachers created during the PD program, such as the teacher reflections to understand the teachers' PD experiences, their epistemological beliefs, and PCK of argumentation. The researcher also collected field notes of classroom observations and written journals or transcriptions of informal conversations about the science teachers' implementation of argumentation instruction, their PCK of argumentation, and epistemological beliefs. Classroom observations were conducted between March – May 2017 in the classrooms of four science teachers who agreed to participate in the extensive data collection part of the study. The timeline for classroom observations was determined based on each teacher's lesson plan. The researcher conducted direct observations through taking field notes to capture the science teachers' classroom practices. After the observations, four science teachers were asked to reflect on the strengths and challenges of their practices through informal conversations or written notes, which also provided data for the teachers' beliefs about teaching and learning science and knowledge of NOS as domain-specific epistemological beliefs, their beliefs about nature of knowledge and knowing, and for the other factors that the teachers considered as influencing the implementation of ADI model. At the end of the study, a semi-structured interview was conducted with four science teachers to validate the teachers' responses on EBS, VNOS-270, and PCK of argumentation assessments. The data from PCK of argumentation assessment, the VNOS-270 questionnaire, the EBS, and interviews (including both informal conversations and semi-structured interview) were compared to the other data sources collected in the initial phases to identify the shifts in the science teachers' epistemological beliefs (both domain-general and domain-specific) and PCK of argumentation and the relationship between these constructs.

All data sources were utilized to develop in-depth profile of each participant's PCK of argumentation, epistemological beliefs, and argumentation instruction. The PCK of argumentation

assessment and VNOS-270 survey were administered three times across the study, before the professional development (PD) program, at the end of the PD program, and after one-year implementation of the argumentation instruction. The surveys taken before the PD program were represented as pre-survey/ assessment, taken after the PD program were represented as post1-survey/ assessment, and taken after one-year implementation were represented as post2-survey/ assessment throughout the study. The data collection methods for each research question were represented on Table 8, and the data collection phases of the study was represented on Table 9. The definitions of data sources were provided in the following section.

Table 8

The data collection methods utilized for each research question

Research Questions	Data Sources
1. How does the participation in one-year PD program influence PCK of argumentation and epistemological beliefs?	PCK of Argumentation Assessment VNOS-270 questionnaire Epistemological Beliefs Survey Teacher created artifacts Informal conversations Semi-structured interviews
2. How are teachers' PCK of argumentation and epistemological beliefs reflected on their practice?	Classroom Observations Field Notes Researcher Notes
3. What other factors do teachers report as influencing the argumentation instruction?	Teacher created artifacts Informal conversations Semi-structured interviews

Table 9

<i>The data collection phases of the study</i>	
Phases (12 months)	Data sources
Phase 1: June, 2016	PCK of argumentation assessment VNOS-270 questionnaire
Phase 2: June – July, 2016	Teacher artifacts during PD program
Phase 3: August – September, 2016	PCK of argumentation assessment VNOS-270 questionnaire
Phase 4: January – May, 2017	Classroom observations Researcher notes Informal conversations
Phase 5: May, 2017	PCK of argumentation assessment Epistemological Beliefs Survey VNOS-270 questionnaire
Phase 6: May – July, 2017	Semi-structured interview

PCK of argumentation assessment³. McNeill and colleagues (2016) focused on the assessment of teachers’ pedagogical content knowledge (PCK) of argumentation to understand the teachers’ needs and support them with better teaching and learning experiences in the incorporation of scientific practices. *A Framework for K-12 Science Education* (NRC, 2012) and the scientific practices as addressed in *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013) and previous research on scientific argumentation informed the design of PCK of argumentation assessment. PCK of argumentation assessment targeted the four main conceptions: Evidence, reasoning, student interactions, and competing claims. The items of the PCK of argumentation assessment were revised twice, and the third (final) version was prepared including four vignettes with 16 multiple-choice and four open-ended items.

³ See Appendix C

Epistemological beliefs survey⁴. The Epistemological Beliefs Survey (EBS) (Wood & Kardash, 2002) was used in order to assess the science teachers' beliefs about the nature of knowledge and knowing (domain-general epistemological beliefs) as more-or-less independent dimensions rather than stages developing in synchrony. To overcome the shortcomings of existing instruments, Wood and Kardash (2002) developed an 80-item questionnaire including 29 items that were unique to Schommer's (1990) original 63-item questionnaire, 22 items that were unique to Jehng, Johnson, and Anderson (1993), and 29 items that appeared on both instruments. Several exploratory factor analyses retained 38-items representing five independent dimensions of beliefs about the nature of knowledge and nature of knowing. Beliefs about nature of knowledge category involved items related to structure of knowledge (11 items) and attainability of objective truth (3 items), and beliefs about nature of knowing category involved items addressing speed of knowledge acquisition (8 items), knowledge construction and modification (11 items), and characteristics of successful students (5 items) (Wood & Kardash, 2002). The items in EBS were responded to on a 5-point Likert Scale (1= strongly disagree, 2= disagree, 3= unsure, 4= agree, 5= strongly agree), and the maximum score on the survey was 190. Wood and Kardash (2002) reported the internal consistency of the dimensions: .74 for Speed of Knowledge Acquisition, .72 for Structure of Knowledge, .66 for Knowledge Construction and Modification, .58 for Characteristics of Successful Students, and .54 for Attainability of Objective Truth, with overall 0.86 reliability of the instrument.

Classroom observations. For the purpose of this qualitative case study design, the researcher observed the science teachers' implementation of argumentation in their natural classroom setting as a participant observer. During the classroom observations, the researcher acted as a pure observer without interacting with the people in the research setting (Dewalt &

⁴ See Appendix D

Dewalt, 2011). The classroom observations took place between March – May 2017 during the spring semester regularly at least once a week (depending on each teacher’s schedule and lesson plan) to collect data about participating teachers’ implementation of argumentation. During the observations, the researcher took field notes on the practices emerged at the time of observation, particularly, focusing on the process of argumentation. First of all, the details of the events and activities were recorded as primary aids to memory (jot notes) (DeWalt & DeWalt, 2011). As soon as after each observation, jot notes were expanded as descriptive, detailed, organized field notes to provide a proper, complete, and detailed information about the physical context, the interactions, implementation of argumentation, and how the teachers translated their knowledge and beliefs into teaching practice (Dewalt & Dewalt, 2011). The researcher paid attention to the use of the structural elements of an argument described on Table 10, the critical aspects of the interactions whether student-student and teacher-student interactions as well as competing claims in small groups and during the whole class discussion were promoted, and the role of the teacher in the facilitation of dialogic interaction during the classroom instruction.

Table 10

The operational definitions of the structural elements of an argument (Sampson et al., 2013)

Component	Definition
<i>Claim</i>	A conclusion, explanation, conjecture, model, principle, or other answer to a research question
<i>Evidence</i>	Data or findings from other studies that have been collected, analyzed, and interpreted in a way that allows for an appraisal of the claim
<i>Justification</i>	A statement that explains the importance of the evidence by making the concepts or assumptions underlying the analysis and interpretation explicit

Views of Nature of Science (VNOS) questionnaire⁵. Lederman and colleagues (1998) provided the review of traditional paper-and-pencil instruments that included forced-choice items (e.g. agree/disagree, Likert-type, or multiple choice) to assess learners' NOS views. Lederman et al. (1998) argued that these forced-choice items on traditional instruments might threaten the validity of the questionnaire since they were prepared with a certain philosophical stance in mind and reflected developers' views and biases. Another criticism was the analysis of the responses through labeling them as "adequate or inadequate" without detailed information about participants' views. In response to these limitations of paper-and-pencil instruments, Lederman et al. (2002) documented the design of an open-ended questionnaire to "elicit, clarify, and probing learners' nature of science (NOS) views in depth" (p. 503). The open-ended questionnaire aimed to address the aspects of NOS as proposed in recent science education reform documents: scientific knowledge is tentative (subject to change); empirically-based (based on the observations of the natural world); subjective (theory-laden); a product of human inference, imagination, and creativity; and socially and culturally embedded (Lederman, 2007). The questionnaire also addressed the distinction between observation and inference and the meanings and relationship between scientific theories and laws (Lederman, 2007). In addition, Schwartz (2007) revised and validated the items from the VNOS-C (Abd-El Khalick, 1998; Lederman et al, 2002) and named the new version of the questionnaire as VNOS-270 (Schwartz, 2007). For the purpose of the intended study, the VNOS-270 (Mesci & Schwartz, 2017; Schwartz, 2007) questionnaire was administered to explore the science teachers' domain-specific epistemological beliefs. Four teachers had already completed the VNOS-270 questionnaire at the beginning and by the end of the PD program. To follow the changes in the teachers' domain-specific

⁵ See Appendix E

epistemological beliefs, participants completed the VNOS-270 questionnaire in May 2017 after one year of implementation of argumentation instruction.

Teacher reflections (informal conversations). The practice of reflection is a critical skill and a valuable research tool to examine the current teaching and learning practices and to develop new implementations towards the resolution of questionable actions (Patton, 2002). Reflective practices require a purposeful act of inquiry that results from a thoughtful process of planning, action, and evaluation in a systematic manner (Clarke, 2007). According to Goodell (2006), reflective practices require consciousness of the strengths and weaknesses of the implementation to make practical decisions about the next act. Each teacher needs to reflect on the teaching goals and strategies, students' prior knowledge, how students learn, and how to assess students' learning.

On each day of the PD program (except the third day), participating teachers reflected on their previous teaching experiences with the use of argumentation, challenges and strengths of their implementation, domain-specific epistemological beliefs, and PCK of argumentation. They also participated in a follow-up meeting in the fall semester to reflect on the strengths and weaknesses of their implementation of ADI model and shared their lesson plans and students' artifacts for analysis and discussion. In the current study, four in-service teachers' reflections from the PD program were included as the data sources of this study. Reflection questions that the teachers responded during the PD program attached as Appendix F. Additionally, as the researcher took field notes, if there were points requiring clarification, the researcher conducted informal conversations after the classroom observations, in which the teacher had opportunity to reflect on the strengths and weaknesses of the implementation addressing PCK of argumentation, epistemological beliefs, and other factors mediating the argumentation instruction. The teachers either wrote their reflections or talked about their experiences. Informal conversations were audio-recorded and transcribed. Sample questions of informal conversations were listed on Appendix G.

Researcher journals. Reflective journals allowed the researcher to make the experiences, opinions, thoughts, and feelings as visible and prominent part of the research design. Merriam (2009) made the case for reflexivity as critical self-reflection by the researcher about the assumptions, worldview, biases, theoretical orientation, and the positionality that might affect the process of investigation. Self-reflective journals addressed the thoughtful processes of being a researcher, as well as captured the changes and developments within the inquiry. The goal was critical self-reflection to enhance the transparency and validity of the inquiry through reviewing the approach continually and eliminating the competing views. In this study, the researcher reflected on each participant's actions and instructional practices as well as the process of data collection, analysis, and management, ethical considerations, and the quality of the research. This process was also essential for the credibility of the research to report any personal and professional information or concerns or thoughts that might influence the results.

Semi-structured interview⁶. Semi-structured interviews were conducted through pre-prepared open-ended questions addressing the line of inquiry and follow-up questions about the statements requiring elaboration (Roulston, 2010). In this study, the researcher conducted semi-structured interviews at the end of the study lasting approximately 40 minutes. The interview included open-ended questions to validate or clarify the teachers' responses on the PCK of argumentation and epistemological beliefs from the previously collected data sources. Researcher notes about participants' responses on the survey or assessment items were utilized during the interview. Interviews were conducted on the telephone and audio-recorded to listen again and transcribe for the analysis.

⁶ See Appendix H

Data Analysis

The study aimed to explore how participating in one-year PD program influenced the development of PCK of argumentation and epistemological beliefs, whether or not they were translated into the classroom instruction, and other factors mediating the implementation of argumentation instruction. The teachers' responses on *Epistemological Beliefs Survey (EBS)* utilized to assess the teachers' domain-general epistemological beliefs, and *VNOS-270 questionnaire*, *informal conversations*, and *semi-structured interview* were utilized to assess domain-specific epistemological beliefs including knowledge of NOS and beliefs about teaching and learning science. The teachers' informal conversations also analyzed to explore other factors that might influence the implementation of argumentation instructional model.

The teachers' responses on the PCK of argumentation assessment, EBS, and VNOS-270 questionnaire provided quantitative data to describe each teacher's knowledge and beliefs; but, the other data sources including PD reflections, informal conversations, field notes, and final semi-structured interview provided qualitative data. The analysis of all data sources addressed the first question to define how epistemological beliefs (domain-general and domain-specific) and PCK of argumentation changed through one-year PD program. Also, the analysis of informal conversations and final interview referred to the third question to explore other factors influencing the implementation of argumentation instructional model. For the second question, the researcher analyzed the field notes taken during the classroom observations and informal conversations about their practice to explore the instances of the teachers' PCK of argumentation and epistemological beliefs reflected on the classroom practice.

The analysis of the data sources involved two different methods including descriptive statistics and constant-comparative method. Descriptive statistics was utilized to assign scores on the teachers' responses on the EBS, VNOS-270 questionnaire, and PCK of argumentation assessment.

Constant comparative method was described as a continuous growth process in which each stage of the analysis transformed itself to the next through focusing on the explanations synthesized at different levels of generality and making logical relations among concepts or set of ideas. Strauss and Corbin (1998) stated, “The researcher begins with an area of study and follows the theory to emerge from the data” (p.12). The process started with the knowledge of earlier work or existing concepts to construct a research question and to gain insights about the literature to be able to collect data. The analysis started with initial coding (Corbin & Strauss, 2008) included both data and theory-driven codes and followed with searching for the most frequent codes to develop categories and to synthesize and validate the relationship across categories. In this study, the teachers’ initial profiles on PCK of argumentation and epistemological beliefs were compared systematically to the teacher reflections collected during the PD program, informal conversations collected during the classroom observations, and final semi-structured interviews to generate the final profile of each teacher in answering the research questions.

There were 20 items in PCK of argumentation assessment. They included five items on each dimension (evidence, reasoning, student interaction, and competing claims); 16 multiple-choice and four open-ended items. The maximum score of the assessment was 20 (maximum score as five on each dimension); each item was scored either 0 (inaccurate) or 1 (accurate) indicating whether the teacher accurately knew the structural elements and dialogic process of argumentation in parallel to the definitions of scientific literature. Descriptive statistics were used to report the teachers’ responses quantitatively on the PCK of argumentation assessment. Additionally, participants addressed their PCK of argumentation during PD reflections, field notes, informal conversations, and final interview. Their qualitative responses were analyzed through constant-comparative method. Through initial coding, theory-driven and data-driven codes are applied to develop categories and themes. Teachers’ PCK of argumentation involved the categories from

McNeill et al. (2017) on the PCK of argumentation, but data-driven codes were also applied that resulted in categories about teachers' knowledge by ADI model. Table 11 included the categories and codes utilized to assess the teachers' PCK of argumentation and argumentation instruction.

Table 11

Conceptions of PCK of Argumentation (Modified from McNeill et al., 2017)

Categories	Sub categories	Codes	Sub Codes
Argument Structure	• Evidence • Reasoning	• Definition • Knowledge of ○ Student Conceptions ○ Instructional Strategies	• General • Other ○ Science Content ○ Academic Language ○ Test-preparation
Dialogic Process	• Student Interaction • Competing Claims		
ADI model	• Specific Stages • Challenge		

The quality of each PCK of argumentation conception was categorized as *high-quality* or *low-quality* (or *limited*) based on the definitions of McNeill and colleagues (2017) on evidence, reasoning, student interactions, and competing claims conceptions in terms of the teachers' knowledge of student conceptions and instructional strategies for argumentation. The teachers' conceptions on PCK of argumentation were coded as *limited* or *low-quality* if the teacher provided unclear or incomplete definition of the conception, addressed student conceptions without detailed description and rationale, and provided instructional strategies that was not able to promote argumentation in-depth. On the other hand, the teachers' conceptions on PCK of argumentation were coded as *high-quality*, if the teacher provided accurate definitions of the conceptions and their connections, described student conceptions about argumentation in detail including the rationale and examples, and indicated instructional strategies that could promote argumentation in-depth such as explanation of how a particular strategy looked like in a classroom context.

The participants' domain-general epistemological beliefs were assessed through the Epistemological Beliefs Survey (EBS) (Wood & Kardash, 2002) that included 38 items with five dimensions (speed of knowledge acquisition, structure of knowledge, knowledge construction and modification, characteristics of successful students, and attainability of objective truth). Each item was scored on a 5-point Likert scale (1= strongly disagree, 5= strongly agree), and the scores on the survey ranged from 0 to 190. The participants' responses on the EBS were classified as either absolutist, multiplist, or evaluativist beliefs about the nature of knowledge and knowing. Absolutist views defined knowledge as isolated pieces of information, multiplist views defined knowledge as subjectivist beliefs addressing the knowledge as subjective, uncertain and depending on personal experience, and evaluativist views defined knowledge as complex based on evidence-based critique of multiple perspectives (Brownlee et al., 2009). The informal conversations as qualitative data were also analyzed to support the teachers' survey responses; the informal conversations also provided data related to teachers' knowledge about source of knowledge.

The data related to participants' domain-specific epistemological beliefs were collected through different data sources including VNOS-270 questionnaire, PD reflections, informal conversations during the classroom observations, and final semi-structured interview. Participants' responses on VNOS-270 questionnaire were classified for each aspect of science based on a continuum representing a range of views from "naïve" to "even more informed" demonstrated through a multiple "+" system (naïve: -, mixed: (+), informed: +, more informed: ++, even more informed: +++)⁷ and scored from one to five. The naïve scientific knowledge addressed the science as objective and culture-free, but the more informed scientific knowledge represented the science as the results of investigations and inferential and creative activities that provided evidence to support the products and that are subject to change (Schwartz, 2007). The scores on each aspect of NOS were

⁷ See Appendix I

assigned based on the continuum to provide descriptive statistics of the results. Additionally, the teachers' qualitative responses on the questionnaires as well as PD reflections, informal conversations, and final semi-structured interview were analyzed using *constant comparative method* to explore the teachers' knowledge of NOS and beliefs about teaching and learning science as domain-specific epistemological beliefs. Data-driven codes are applied to develop categories, which aligned with the published literature. Table 12 included the categories and codes developed through data- and theory-driven codes to assess the teachers' epistemological beliefs.

Table 12

Conceptions of Epistemological Beliefs (Modified from Buehl, 2008; Abd-El-Khalick, Waters, & Le, 2008; Luft & Roehrig, 2007)

Categories	Sub categories	Codes and Sub Codes
Domain-general beliefs	Beliefs about nature of knowledge	Structure of Knowledge Attainability of Objective Truth
	Beliefs about nature of knowing	Controlling factors • Characteristics of Successful Students Process of knowing • Knowledge Construction and Modification • Speed of Knowledge Acquisition • Sources of Learning
Domain-specific beliefs	Knowledge of NOS	• Empirical-embeddedness • Creativity and imagination • Tentativeness • Subjectivity • Sociocultural • The difference between observation and inference • The difference between theory and laws
	Beliefs about teaching & learning	• Learning ○ Indicators of learning ○ Maximize student learning • Teaching ○ Role as a teacher

The qualitative data sources such as informal conversations and final interview were analyzed to understand other factors that might mediate the argumentation instruction. The

researcher looked for the events or instances that the teachers explained, which influenced argumentation instruction positively or negatively throughout the year. The informal conversations were analyzed to explore the factors mediating the implementation of ADI model. Table 13 (modified from Prime & Miranda, 2006) represented the categories and codes through data- and theory-driven codes to determine the other factors.

Table 13

<i>Factors mediating the implementation of ADI model (Modified from Prime & Miranda, 2006)</i>	
Categories	Definition
Beliefs about Student Ability	Description of how teachers' beliefs about student ability influenced the implementation of ADI model referring to: Process skills, prior knowledge, student characteristics, attitudes
District and Standards	Description of how district and standards influenced the implementation of ADI model
School Context	Description of how school context influenced the implementation of ADI model
Curriculum and Testing	Description of how curriculum and testing influenced the implementation of ADI model

The primary data for the analysis of classroom observations included the field notes and researcher reflections on the instructional practices. The data from informal conversations was also utilized to make clarifications on the teachers' instructional decisions or behaviors. The data was organized on chronological order from the first to the last observation included observation notes and researcher notes supported by informal conversations, pictures of student and the teacher created artifacts, and samples of learning tasks to support the researcher interpretation. The timeline for classroom observations and informal conversations was presented on Appendix J. The observation data was analyzed considering how the teachers incorporated argumentation instructional model (Argument-Driven Inquiry model) into practice (whether adapted or modified). The researcher

utilized the coding schemes (Table 11, 12, and 13) developed for PCK of argumentation, epistemological beliefs, and other factors to present classroom observation profile for each teacher.

In this study, the knowledge acquired from each aspect of the study informed each other in the triangulation process to build explanations and make revisions iteratively to answer the research questions. The researcher compared the findings of each data collection method to the previous results to describe the relationship between teachers' epistemological beliefs, PCK of argumentation, and argumentation instruction and trace the change in teachers' epistemological beliefs and PCK of argumentation. Table 14 explained the design and timeframe of the study.

Table 14

Design and timeframe of the study

	Phase	Procedure	Process
June (2016)	Quantitative Data Collection	PCK of argumentation VNOS-270	Descriptive Statistics
June (2016) July (2016)	Qualitative Data Collection	Teacher reflections	Open-coding and theme development within case and cross-case comparison
August (2016) September (2016)	Quantitative Data Collection	PCK of argumentation VNOS-270	Descriptive Statistics
January – May (2017)	Qualitative Data Collection	Classroom observations Researcher notes Informal conversations	Open-coding and theme development within case and cross-case comparison
May (2017)	Quantitative Data Collection	PCK of argumentation Epistemological Beliefs Survey VNOS-270	Descriptive statistics
May – July (2017)	Qualitative Data Collection	Semi-structured interviews	Open-coding and theme development within case and cross-case comparison
Triangulation of data, analysis, and interpretations to develop within-case and cross-case profiles			

Ensuring the Quality of the Research

Teddlie and Tashakkori (2009) provided an integrated framework including credibility, transferability, dependability, and confirmability to incorporate the different aspects of quality of research. The credibility of a study was analogous to internal validity, which dealt with the plausibility of research findings, as well as the strength of the research to uncover the complexity of human behavior, to understand the perspectives of those involved, and to provide a holistic interpretation of the phenomenon of interest (Merriam, 2009). The researcher utilized multiple data collection methods. Classroom observations were supported by the teachers' reflections, audit trail, data from survey and questionnaire instruments related to targeted constructs, and informal conversations for a chain of evidence in investigating the relationship between participants' epistemological beliefs, PCK of argumentation, and the enactment of argumentation. The researcher created space for the participants' questions, concerns, and feedback to learn whether the findings were meaningful and comprehensive and to build on the data from the participant reflections to enhance the credibility.

Transferability was analogous to the external validity that refers to the generalizability of the findings to identical settings. The researcher needed to provide sufficient descriptive data to make transferability possible across different settings, individuals or groups, and texts or artifacts (Teddlie & Tashakkori, 2009). The researcher provided thick and rich descriptions of the sample and the research context and write accessibly to enhance the transferability. Additionally, *dependability* (consistency) was analogous to reliability and addresses the extent of the study design, as well as the research methods to examine whether the process was reasonable and provides consistent conclusions (Teddlie & Tashakkori, 2009). The data sources of the study, the PCK of argumentation assessment (McNeill et al, 2016), the Epistemological Beliefs Survey (Wood & Kardash, 2002), and the VNOS-270 questionnaire (Schwartz, 2007) had already been

validated and published. The PCK of argumentation assessment included both open-ended and closed-ended items. During the analysis process, qualitative items were quantized using the rubric provided by McNeill and colleagues (2017), depending on the quality of the conceptions of PCK of argumentation. The reliability of the data conversion was established through comparing 25% of the converted data between the researcher of this study and a science education faculty member and negotiating the disagreements.

Confirmability referred to the objectivity of the study and determined how “the interpretations are supported by the results and are internally coherent” (Teddlie & Tashakkori, 2009, p. 295). Each method of data collection was dependent on and informed the following data collection for triangulation of multiple sources to uncover the consistencies, illuminate the phenomenon from various aspects, and eliminate subjective biases and assumptions in an iterative process. For example, the participants completed the PCK of argumentation assessment and VNOS questionnaire at the end of the study, and then a semi-structured interview was conducted to validate their responses and trace the change in their epistemological beliefs. For objectivity, all data sources were analyzed at the end of the study to reduce the subjective biases. Constant comparison of the findings in each phase of the study assisted to revise the explanations through comparing the evidence and triangulating the results. As Hoepfl (1997) indicated, confirmability could be provided through “raw data, analysis notes, reconstruction and synthesis products, process notes, personal notes, and preliminary developmental information” (p. 14). The verbatim quotes were utilized from the interviews and teacher reflections to provide raw data in the results section. The researcher also provided detailed information about the analysis, and products and process notes from the study.

Ethical considerations. Besides finding the credible answers to research questions, research designs must consider the well-being of participants and establishment of the quality of ethics. Organizations or institutions required Institutional Review Boards (IRBs) to evaluate the

appropriateness of the research projects, protect the research participants, and conducting regular reviews of the projects (Teddlie & Tashakkori, 2009). The researcher should consistently reflect on the methods and the design of the study to track the unpredictable, but ethically significant events. After the teachers became volunteers to participate in the study, they provided an informed consent form to inform them about the research procedures, purpose, confidentiality, potential risks, and benefits. Informed consent forms involved the plan and the information about the privacy related to the anonymity and confidentiality (Teddlie & Tashakkori, 2009). The confidentiality of the consent form included the information about using pseudonymous names and securing all the data in a locked drawer or password protected computers. Pseudonymous names were utilized to ensure the confidentiality. During classroom observations, the process of collecting data did not influence the teaching actions or decision-making process for the implementation of argumentation; and no data were collected from the students, and students' learning process was not disturbed.

Role of the researcher. An educational researcher should strive for the highest ethical standards in doing research including having a responsibility to scholarship such as avoiding plagiarism, falsification of information, ensuring accuracy, and uncovering the methodological strengths and limitations (Yin, 2014). Researcher is the primary instrument of the data collection process in the qualitative studies: The research process is influenced by the ideas, biases, and interpretations of the researcher; the researcher should make her/his biases explicit (Patton, 2002). Additionally, a qualitative researcher can have different roles in the research field as an insider (emic) or an outsider (etic) that can influence the findings and interpretations. Insiders' view of the context of the study and the conclusions would be different from the outsiders' approach to the study. According to Patton (2002), a complete participant can develop an insider's view through involving in a community to learn, think, see, feel, and act as part of culture, from an emic perspective, whereas an etic approach has an objective view without

influencing the meanings that participants bring in the study. In this qualitative case study, the researcher was considered as etic (outsider), who conducted classroom observations as a pure observer without having any interaction with the participants in their natural setting or influencing their decision-making process during the instruction.

Researcher's views of PCK of argumentation and epistemological beliefs. The researcher received an integrated B.S. and M.S. High School Teaching Physics Diploma and Master of Science in physics from two different international institutions. The researcher's interest on teaching and learning argumentation and PCK began about two years ago. As a doctoral student, the researcher was interested in the teachers' pedagogical content knowledge (PCK) of argumentation and how teachers translate their PCK of argumentation into classroom practice. The literature review on science teachers' challenges of implementing the argumentation indicated that teachers' epistemological beliefs might serve as amplifier or filter for the argumentation instruction. Therefore, the researcher was interested in examining these constructs, PCK of argumentation, epistemological beliefs, and argumentation instruction to understand how teachers' epistemological beliefs and PCK of argumentation were reflected on or absent from the implementation of argumentation.

A national report commissioned by the National Research Council, *Taking Science to School: Learning and Teaching in Science in Grades K-8* (NRC, 2007) emphasized the significance of scientific argumentation in the process of learning science as a significant component of scientific literacy to encourage students' participation in cognitive, epistemic, and social aspects of scientific thinking and reasoning (Cavagnetto, 2010). This vision led to the development of *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012) as well as the development of *Next Generation Science Standards* (The NGSS Lead States, 2013). Considering the recommendations of reform documents, the researcher believed that students should engage in

authentic science learning experiences; students should engage in the construction and critique of knowledge claims and learn how to support their claims with high-quality evidence.

As one of the core epistemic practices of science, incorporating argumentation into classroom instruction could encourage students' participation in cognitive and metacognitive processes, develops communication skills, fosters critical reasoning, and supports their understanding of how knowledge is developed in the scientific community (Cavagnetto, 2010; NRC, 2012; Osborne, 2010). The researcher believed that science teachers needed to develop a knowledge base and have instructional resources for successfully integrating argumentation into science teaching to engage students in scientific practices and accommodate students' learning needs. According to the researcher, science teachers should know how to evaluate students' arguments and support students to use evidence to justify their claims. Science teachers should be aware of the appropriate instructional strategies to address students' challenges in the use of argumentation, help them make a connection between claims and evidence, critique each other's ideas, and provide alternative claims.

Moreover, the researcher believed that individuals held both domain-general and domain-specific epistemological beliefs. Domain-general epistemological beliefs were referred to individual's beliefs about nature of knowledge and knowing; so far, they have been studied with two theoretical frameworks: developmental and multidimensional frameworks. The researcher believed that the unidimensionality approach might filter the different aspects of teaching and learning, and epistemological beliefs involved a system of more or less independent beliefs. Considering multidimensionality of epistemological beliefs, the researcher believed that learning was a complex and gradual process, and time and effort were required for learning to occur. The researcher also believed that knowledge was complex, and included interrelated concepts with multiple connections, and it is subjected to questioning and change.

Individuals might have different conceptions depending on the academic disciplines. Science teachers might or might not hold similar domain-general and domain-specific beliefs, and their knowledge about nature of science and scientific knowledge might influence their teaching approaches and implementation of specific instructional strategies. The researcher believed that scientific knowledge was tentative and subject to change with new evidence found through new investigations or the developments in technology; scientific knowledge was based on the observations of the natural world or empirically-based and involved human imagination and creativity dependent on the observations and inferences; scientific knowledge was subjective or theory-laden that scientists' prior knowledge, experiences, theoretical perspectives, and values influenced the ways they designed their research, conducted investigation, and interpreted the results; and scientific knowledge was socially and culturally embedded that science was influenced by the power structures, religion, politics, religion, and economic factors in a society. The distinction between observation and inference and the relationship between scientific theories and laws were the other aspects of nature of science. Observations and inferences guided scientists' interpretations, in which the former was directly done through senses, whereas the latter referred to the interpretations of the observations not accessible to senses. In addition, according to Abd-El-Khalick, Waters, and Le (2008), laws were statements that describe the relationships of the observations, whereas theories were inferred explanations about the observed phenomena. Scientific theories and laws were different types of scientific knowledge; there was no hierarchical relationship between them, and they could not be converted to each other (Abd-El Khalick et al., 2008). The researcher believed that there was no certain scientific method, and scientists engaged in a range of methods to build scientific explanations.

CHAPTER IV

RESULTS

The overarching aim of the study was to explore whether any change occurred in the urban science teachers' epistemological beliefs and PCK of argumentation through one-year professional development on argumentation instruction. The study also aimed to determine if and what practical aspects of epistemological beliefs and PCK of argumentation were related and how they were translated into classroom instruction. Additionally, the research explored what other factors might influence the argumentation instruction. Data were collected through questionnaires, interviews, classroom observations, and teacher-created artifacts and analyzed through descriptive statistics and constant comparative method. To address these objectives, each participant's PCK of argumentation and epistemological beliefs profile was reported as separate cases, and then a cross-case analysis was conducted to discuss the similarities and differences across the participants.

The research questions guiding the present investigation were:

1. How does the participation in one-year PD program influence science teachers' PCK of argumentation and epistemological beliefs?
2. How are teachers' PCK of argumentation and epistemological beliefs reflected on their practice?
3. What other factors do teachers report as mediating the argumentation instruction?

Case-1: Asia

Asia was a veteran teacher with 16 years teaching experience in various disciplines including literature, mathematics, physics, chemistry, biology, environmental science, and forensic science. She had a bachelor's degree in psychology. Asia was teaching in a Title-1 high

school in an urban district located in the southeast region of the USA. Her school had a unique context working with special education students from diverse backgrounds, who stayed in her class for a limited period. At the time of the study, her class involved maximum 12 students from all grades studying different science subjects, and the one-class period was limited to 50 minutes.

PCK of Argumentation

Asia's PCK of argumentation scores was presented in Table 15, which showed the results of pre-, post1-, and post2- PCK of argumentation assessments for four teachers on structural and dialogic aspects of argumentation. Her scores were consistently high-quality over the course of the study on both the structural elements and dialogic aspect of argumentation even though she indicated limited views on the evidence conception on pre- and post2- assessments. The detailed information about Asia's PCK of argumentation was provided below.

Argument Structure. Asia's responses on the pre- and post2- PCK of argumentation assessments indicated her limited knowledge of evidence conception that she provided two correct responses on the PCK of argumentation assessment. However, the improvement was observed in her knowledge of evidence conception on the post1- evaluation in parallel to her explanations during the PD program, the informal conversations, and final interview. She provided an accurate definition of evidence conception during the PD program and stated,

"Evidence is the data my students collect during the lab. It can be qualitative and quantitative. Evidence that is high quality, accurate, precise, and has more than one trial."

She elaborated on her explanations on the final interview and stated,

"I think it depends on what type of evidence, I think how precise the measurements are, how accurate they are, how much data is taken, how many different times, how you chose your subject, what your sample size is. All of those things are affecting the evidence."

In this quotation, Asia indicated that high-quality evidence depended on the accurate and precise data collection including the dependent and independent variables, the number of the data, sampling strategies, and repeated trials.

Table 15

Results of PCK of argumentation assessment for four teachers from pre-survey (P1), post-survey (P2), and delayed-post survey (P3) in total and for the argumentation conceptions: 1A: evidence, 1B: reasoning, 2A: student interactions, and 2B: competing claims

Teacher	Assessment	Total	1A	1B	Structural	2A	2B	Dialogic
Asia	Pre	12	2	3	5	4	3	7
	Post1	15	4	4	8	3	4	7
	Post2	13	2	4	6	3	4	7
	Change	+1	0	+1	+1	-1	+1	0
Bella	Pre	12	2	5	7	1	4	5
	Post1	6	4	1	5	1	0	1
	Post2	11	4	3	7	2	2	4
	Change	-1	+2	-2	0	+1	-2	-1
Eva	Pre	0	0	0	0	0	0	0
	Post1	7	0	2	2	2	3	5
	Post2	6	2	2	4	1	1	2
	Change	-1	+2	0	+2	-1	-2	-3
Olivia	Pre	12	3	4	7	3	2	5
	Post1	0	0	0	0	0	0	0
	Post2	0	0	0	0	0	0	0
	Change	0	0	0	0	0	0	0

Asia also had high-quality knowledge of reasoning conception throughout the study. She defined reasoning as, “*including the evidence and the background information that is applicable and how evidence and background information are connected.*” She addressed the reasoning as a clear connection between evidence, analysis, and underlying scientific concepts.

Dialogic Process. Asia’s responses on three PCK of argumentation assessments indicated her high-quality knowledge of dialogic process over the course of the study. During the informal conversations, she emphasized the dialogic process through linking to argument structure and stated,

“Argumentation is a critical part of science teaching and should be employed at every grade level. It allows students to conduct labs, create their conclusions, prove those conclusions with evidence, and then revise their work based on peer feedback. It teaches students to look critically at the world and themselves and to accept differing viewpoints and learn from those other viewpoints. Both of which I think are critical life skills for today’s world.”

Asia defined argumentation as a social process that students looked at multiple perspectives, provided critical feedback on each other’s work, convinced others about the relevancy of their claim, and built on other people’s ideas while working in groups.

Knowledge of Student Conceptions. Asia’s three PCK of argumentation assessment responses and reflections during the PD program indicated her limited understandings of student conceptions of argumentation. However, the increase in Asia’s knowledge of evidence conception during the informal conversations and final interview reflected the positive influence of explicit argumentation instruction to develop knowledge of students’ challenges for argumentation. Asia stated,

“Students made a claim, and they had evidence, but their claim and evidence were not related. And students used the evidence to give proof to a claim that was not connected to the evidence.”

The teacher indicated that students had difficulty in providing relevant evidence to support the claim, and they might find out that their claim was wrong after collecting sufficient evidence. She added,

“What kind of evidence is good evidence. A lot of the kids thought that they could just do one trial and then that would be enough. That needs to be a discussion... What kind of trials are enough, what kind of test subjects are enough? Can you test on a white man and say that applies to all people or test on little kids and say that applies to older people?”

The teacher thought students had challenges in providing high-quality evidence. She felt students needed to collect multiple data, make accurate measurements, and consider sampling strategies. For reasoning conception, she held limited knowledge of student conceptions and pointed out students' difficulty in providing proper justification such as making the connection between claim and evidence and synthesizing the information.

Asia also proposed accurate views to address students' challenges on the social aspect of argumentation over the course of the study and stated,

“Kids that are really good at code learning get frustrated with ADI. They are like, ‘what to do, you are not telling what to do.’ ... A lot of kids feel very challenged and seem to really like ADI because it gets them a chance to ... decide on their own what they will do.”

Asia thought students were used to learning through direct instruction and exposed to multiple choice questions or cook-book type labs with the precise set of directions that they got quickly frustrated with the process of scientific argumentation, particularly ADI model, as they have never been exposed to science activities in that rigor. She emphasized that students had difficulty in articulating their thoughts through oral or written communication, which also linked to their challenge in receiving feedback from their peers.

Knowledge of Instructional Strategies. Asia suggested similar instructional strategies indicating her limited knowledge of instructional strategies that were not able to promote argumentation in-depth. Asia considered using scaffolding strategies; for example, modeling data collection and analysis and using the ADI poster to define the structural elements of an argument. She also thought using the graphic organizers including topic sentence or questions to answer piece by piece and teaching how to cite the evidence from the text. For the reasoning conception, Asia mainly focused on the development of academic language and background knowledge through

integrating visual resources and different levels of reading passages as well as providing the real-life examples. On the dialogic process, Asia considered assigning students into groups based on their strengths such as “*strong writer with strong thinker*” and setting up guidelines in providing and receiving feedback to promote productive discussions among peers. The teacher suggested eliciting students’ ideas through giving situations about a natural phenomenon, asking probing questions, and incorporating think-pair-share activities.

Knowledge by ADI Model. Asia described the process of ADI model as a way to experience the scientific practices and develop critical thinking. She thought ADI investigations provided a context to conduct science experiments through asking questions, collecting data, drawing conclusions based on evidence, writing scientific papers, and providing and receiving feedback to revise their work. She added that the instructional model scaffolded the NOS instruction as well. Referring to the specific stages, she thought students needed to consider the independent and dependent variables, percent error, qualitative and quantitative data, sample size, and measurements during the *Design of Investigation* and *Data Collection* stage. Asia pointed out the *round robin* and *group presentation* as methods to integrate into the *Argumentation Session* stage. She defined *round robin* as rotating around each group to look at each other’s whiteboards and provide feedback based on the subjectivity aspect of science. The teacher added that *round robin* was appropriate for the large class size, whereas *group presentation* method was more relevant for small class size.

Moreover, Asia defined *Explicit and Reflective Discussion* stage as an opportunity to talk about what students did and what they could do differently as well as to teach science concepts, nature of science, and cross-cutting concepts. She thought “*Writing an Investigation Report*, and *Peer Review*” stages encourage students to communicate ideas and evaluate the papers critically and objectively through peer review rubric as a PD resource for writing the reports and

reviewing the papers. Asia also pointed out her difficulty in modeling the data collection, defining the structural elements of argument structure, and explaining the cross-cutting concepts as well as creating her own ADI activity or converting an inquiry-based lab into an ADI activity.

Epistemological Beliefs

Domain-General Beliefs. Asia indicated evaluativist views on each dimension of EBS on her beliefs about nature of knowledge and knowing. Table 16 presented the scores of four teachers' EBS responses. There was a consistency between the survey responses and Asia's explanations during the informal conversations and final interview. Asia thought the structure of knowledge was complex rather than simple with one right answer and developed through expanding the prior knowledge with other people's ideas, lots of evidence, and discussion in time. Her beliefs about the certainty of knowledge reflected her views about tentativeness of knowledge that scientists might not get to the truth even though they tried hard. During the final interview, she stated,

"People learn things about the natural world... and they pass that knowledge on either orally or through writing or through technology... you just keep on building on knowledge of the past learning from the people around you."

Asia indicated evaluativist beliefs about nature of knowledge that different knowledge claims might be evaluated based on individual's prior knowledge and through collecting multiple evidence. Furthermore, Asia's beliefs about nature of knowing were categorized as controlling and influencing factors and process of knowing. For controlling factors, she indicated mixed views that learning required both innate ability and hard work. Asia thought students might not understand things easily and might need to work hard to be successful rather than memorizing facts. For process of knowing, she reported,

Table 16

Results of EBS survey for each teacher on each item on each dimension of EBS

Speed of Knowledge Acquisition- R													Total
	Q3	Q7	Q11	Q16	Q18	Q24	Q34	Q38					
Asia	4	4	4	4	4	4	4	5					33
Bella	5	5	5	4	4	4	5	4					36
Eva	4	3	2	5	3	5	5	5					32
Olivia	4	4	4	4	4	4	4	4					32
Characteristics of Successful Students- R						Attainability of Objective Truth-R							Total
	Q14	Q17	Q19	Q29	Q35	Q1	Q9	Q27					
Asia	4	4	4	4	4	2	4	4					30
Bella	1	4	2	2	4	4	3	3					23
Eva	5	2	5	5	5	2	2	5					31
Olivia	3	4	4	3	4	4	3	3					28
Structure of Knowledge- R													Total
	Q4	Q5	Q12	Q13	Q21	Q26	Q28	Q30	Q31	Q33	Q36		
Asia	3	4	2	4	3	2	5	4	4	4	2	37	
Bella	2	3	1	5	1	3	5	4	2	4	1	31	
Eva	3	4	3	3	1	3	4	3	5	5	2	36	
Olivia	4	4	3	3	4	4	4	4	3	4	3	40	
Knowledge Construction and Modification												Total	
	Q2	Q6	Q8	Q10	Q15	Q20	Q22	Q23	Q25	Q32	Q37		
Asia	4	2	4	4	4	4	3	4	4	4	4	41	
Bella	3	4	5	5	5	4	4	4	4	4	4	46	
Eva	4	3	3	5	3	2	3	5	5	3	5	41	
Olivia	3	4	4	4	4	4	4	4	4	3	4	42	

“You are constantly learning, and it is done in thousands of different ways by hearing, seeing, touching, all the senses are involved in learning. Then, how people actually retain that knowledge depends on the person, and their prior knowledge... and how they can tie to the frameworks that they already have.”

Asia held views about the process of knowing including her mixed beliefs about controlling factors of learning as innate ability and perseverance and the process of knowing as learning occurs in a gradual process developed through experience and using the accumulated findings such as articles and internet.

Domain-Specific Beliefs. Knowledge of NOS. The analysis of three VNOS-270 survey responses indicated that Asia's views did not change significantly in one year. Table 17 presented the changes of four teachers' VNOS-270 responses across three implementations. Asia consistently had mixed knowledge of "*tentativeness, creativity and imagination, empirical-embeddedness, sociocultural, and the difference between theory and law*" aspects throughout the study. There were also changes occurred on "*the difference between observation and inference and subjectivity*" aspects of science during the project. Asia indicated informed views on "*the difference between observation and inference*" at the beginning and end of the study even though her explanations indicated her mixed views on this aspect at the end of PD program. A decrease was observed in her understanding of the *subjectivity* aspect that her informed views before the PD program shifted to mixed views by the end of the study. On the final interview, the teacher linked *empirical-embeddedness* to the *tentativeness, creativity and imagination, and the difference between observation and inference* aspects of science and stated,

Table 17

The results of VNOS-270 survey for four teachers on each aspect of NOS^a

	Tentativeness			Creativity			Subjectivity			Observation/ inference			Empirical			Theory/ Law			Sociocultural		
	P1 ^b	P2 ^b	P3 ^b	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
ASIA	(+)	(+)	(+)	(+)	(+)	(+)	+	(+)	(+)	+	(+)	+	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
BELLA	(+)	-	(+)	(+)	(+)	(+)	(+)	(+)	(+)	-	(+)	(+)	-	(+)	(+)	-	-	(+)	(+)	(+)	+
EVA	(+)	+	(+)	-	(+)	(+)	(+)	(+)	(+)	-	-	-	(+)	(+)	-	(+)	(+)	(+)	-	-	-
OLIVIA	(+)		(+)	(+)		(+)	(+)		(+)	(+)		(+)	(+)		(+)	-		(+)	-		-

a: “-” represents naïve views, “(+)” represents mixed views, “+” represents informed views.

b: “P1” represents pre- VNOS-270 questionnaire taken at the beginning of the professional development program, “p2” represents post1- VNOS-270 questionnaire taken after the one-week summer workshop, and “p3” represents post2-questionnaire taken at the end of the professional development program

“I think that is where a lot of creativity plays into it. The way they discovered proton, the way they discovered the electron, things that I would never think, I cannot imagine someone thinking of the way that they can investigate ideas like Kepler, I would never think of looking at a star and see when that star is dark to try to define planet.”

Asia addressed how scientists used their creativity to investigate the scientific phenomena that could not be seen directly such as exploring the effect of dark matter on stars and planets. She also made the connection between sociocultural and subjectivity aspects of science and stated,

“People depending on their background come to scientific problems with different areas and expertise, and they might see different things in the same set of data.”

Asia’s mixed views on different aspects of NOS indicated the alignment between her beliefs about nature of knowledge as complex and integrated and the construction of scientific knowledge through designing the experiments and observations and revising solutions based on new evidence.

Beliefs about teaching and learning. Asia understood that students learned the concepts through formative assessments such as exit tickets and rubrics. She particularly emphasized work products such as students’ questions, explanations, their investigation reports or whiteboards as the indicators of learning. Asia defined her role as a facilitator and stated,

“I think, my role is a facilitator. I am supposed to guide them how they look at the information and how they collect data and how they present it. I am not trying to give it to them directly; I am trying to help them discover on their own.”

Additionally, Asia considered teaching argumentation as a way to maximize learning to promote collaboration and critiquing each other’s ideas to make students feel appreciated, understood, and validated. She added,

“Patience, time to be themselves, acceptance, emotional support, positive feedback, scaffolding, differentiation, gradually increasing expectations, built in incentives, etc. are the supports they would need off.”

The teacher suggested incorporating the differentiation techniques such as real-world examples, discrepant events, and hands-on activities to hit all different learning styles. She also preferred lecturing through demonstrations and visual sources to cover the standards.

Summary. Asia defined ADI model as a way to support students’ engagement in the works of scientists including the design of the experiment, data collection and analysis, argument construction, and communicating the ideas through a discussion of the alternative explanations or writing. The results indicated that Asia showed improvement on her PCK of argumentation, but no significant change was observed in her epistemological beliefs throughout the study. Her limited understanding of evidence conception on the pre- and post2- PCK of argumentation assessments were high-quality on the post1- survey and during the informal conversations and final interview. Her definitions of justification conception and dialogic process were high-quality and consistent. She provided limited knowledge of instructional strategies that were not able to promote argumentation in-depth. Her limited understanding of student conceptions of argumentation was high-quality towards the end of the study that she provided the rationales for students’ challenges.

There was a consistency between PCK of argumentation and epistemological beliefs by the end of the study. Her PCK of argumentation was parallel to her domain-general epistemological beliefs as she thought knowledge was complex and integrated and learning occurred in a gradual process through experience in parallel to her emphasis for integration ADI instructional model to teach the science content. Asia’s PCK of argumentation was also consistent with her domain-specific epistemological beliefs that she defined science as a way of

knowing and thought science was informed by scientists' creativity and imagination, subjectivity, and social and cultural values in designing the experiments and observations and revising solutions based on new evidence to develop scientific knowledge. And, she supported students' active involvement in the dialogical discourse around scientific phenomena through justified arguments by modeling the use of structural elements of an argument, promoting student interaction, and eliciting alternative ideas rather than acting as the sole source of information. However, belief about her role as a facilitator and evaluativist views about nature of knowledge were not parallel to her belief about nature of knowing that she thought learning was an innate ability, her beliefs about maximizing student learning through lecturing, and using the internet and textbook as the source of knowledge to reach the information quickly and easily.

Teaching by Argumentation Instructional Model: Aligned Enactment

Data collection around Asia's teaching practice included 17 hours of classroom observation to understand how the PCK of argumentation and epistemological beliefs translated into her instructional practices. Within these classroom hours, two ADI investigations were observed related to "Potential Energy" and "Memory and Stimuli" topics. Asia's implementation of the ADI stages aligned with what the model was intended even though there were a few improvising conditions. She did not do the "Stage 8: Revision and Submission of Investigation Report" stage due to time limitations. In two ADI activities, Asia utilized similar strategies and addressed both the structural and dialogic aspects of argumentation in parallel with her PCK of argumentation. When she did not implement an ADI activity, she preferred teacher-centered instruction to cover what students needed to know based on the standards similar to her beliefs about maximizing student learning. Table 18 presented the type of enactment and implemented and observed ADI activities in each teacher's classroom in one year.

Table 18

Enacted and observed ADI activities and the type of enactment for each teacher

	Implemented	Observed ADI activities	Enactment
Asia	Environmental Change and Evolution Mystery Cube How to jump action figure higher Memory	How to jump action figure higher Memory	Aligned
Bella	Memory and Stimuli	Memory and Stimuli	Modified
Eva	Potential Energy Surface area- friction Electricity Magnetism	Electricity Magnetism	Modified
Olivia	<u>Force, motion, energy</u> Design Challenge; Mass and Free Fall; Potential Energy <u>Cells and Osmosis</u> Osmosis and Diffusion; Normal and Abnormal Cell Division; Memory and Stimuli; Inheritance of Blood type	Teacher created ADI activity Inheritance of Blood type	Modified

Asia focused on the structural aspect of argumentation during the “*Development of a Method and Data Collection*,” “*Data Analysis and Development of a Tentative Argument*,” and “*Writing an Investigation Report*” stages. She acted as a facilitator aligning with her beliefs about the role as a teacher; she moved from group to group to guide students’ design of experiment and data collection. For example, she asked, “*How will you investigate the guiding question? How many times do you need to collect data? Are you using the same sequence for each person?*”

The teacher emphasized that students needed to consider the research question throughout the investigation and to make reliable measurements to develop high-quality evidence. During the “*Development of Argument*” and “*Writing an Investigation Report*” stages, she utilized the ADI poster as a model to explain the argument structure and stated,

“Claim is what you think will happen with your data. The evidence is important when you analyze the data, shows if there is a trend occurring in the data. Justification is why the evidence supports what you are saying, please refer to the information what you have read at the beginning. How do you know that this will give more energy? What are some important ideas from the text? You can find some evidence from the lab text or reading. You should talk to each other and look at other’s justifications to exchange ideas.”

In this quotation, Asia explicitly defined evidence and justification conceptions, explained how to improve the quality of their arguments, and prompted students to cite evidence from the text. Her integration of the structural elements of an argument was parallel to her knowledge of argument structure including student conceptions and instructional strategies.

Furthermore, Asia promoted dialogic process during the “*Argumentation Session*,” “*Identification of Task*,” and “*Explicit and Reflective Discussion*” stages. At the “*Argumentation Session*,” she encouraged students to provide both positive and constructive feedback and stated,

“Please provide feedback on the work, not the person. Listen to each group’s presentation, provide feedback on the things that you can suggest, things that you like, and on the critical statements about how they designed their investigations, how they collected and analyzed data, and how they presented on the whiteboard.”

Asia modeled how to provide the positive and constructive feedback and added,
“You can start a positive feedback by saying, ‘I like your claim and evidence...’ and a constructive feedback by saying, ‘I like what you did, but...’”

The teacher focused on promoting student interaction through encouraging students to collaborate to share, evaluate, and revise the structural components of arguments through listening to what each group has done and critiquing and building off of each other’s ideas.

Asia also addressed students’ competing claims about scientific principles, crosscutting concepts, and NOS during the *“Identification of the Task”* and *“Explicit and Reflective Discussion”* stages as well as while lecturing when she did not do an ADI activity. The whole-class discussions in these stages were in the form of *“Triadic Dialogue”* including short student responses with teacher elaboration. For example, Asia emphasized the areas that students needed to improve on their posters during the *“Explicit and Reflective Discussion”* stage and stated,

“You need to refer to the information or lab text that you read at the beginning of the ADI to improve the justification.”

Then, she addressed the NOS, particularly work of scientists through asking,
“Why do we share science with others? Why do you present to other students in the classroom? Do you think what Einstein did was perfect?”

Her knowledge of NOS as domain-specific beliefs was translated into classroom instruction in limited ways. Asia emphasized the design of investigation and data collection and analysis to

address the empirical-embeddedness aspect and talked about how scientific claims might change with new evidence to address the tentativeness aspect of science. She also discussed subjectivity of science that students could evaluate each other's work based on their own perspectives in parallel to her beliefs about the attainability of objective truth. However, Asia did not focus on the creativity and imagination aspect in any part of the investigation, but she preferred concentrating on students' enthusiasm rather than the quality of their work. Aligning with her beliefs about teaching and learning science, she evaluated students' products- their questions, explanations, papers, and posters as indicators of their learning. The teacher encouraged them to work together while doing hands-on activities and listen to each other's ideas during discussions to maximize their learning. She acted as a facilitator in parallel with belief about her role as a teacher, but she also lectured to teach the content when she did not do an ADI activity. Asia integrated her evaluativist domain-general beliefs in parallel to her PCK of argumentation as she thought learning occurred through experience, and knowledge was complex and integrated through the dialogic process. She also utilized scientific articles, online education websites, and Youtube videos in parallel with her belief about the source of knowledge as accumulated findings.

Factors Influencing the Argumentation Instruction

Asia talked about various factors effective on the argumentation instruction. She addressed her beliefs about students' ability in engaging in argumentation activities and stated,

“My kids don't have great social skills and the ones that do have good social skills tend to overreact to criticism.”

She indicated that students' low reading and social skills, as well as their emotional and behavior problems, might discourage them to learn through ADI activities. Asia also addressed the relationship between ADI model and standards, and stated,

“All the standards ... are related to ADI. So, a lot of the standards for incorporating literature and writing into science have to do with ADI. And then also the larger concepts the crosscutting concepts are all in everything you do in ADI...”

She indicated that standards were related to the ADI model, which incorporated literature, writing, and crosscutting concepts into science teaching. For the context of the school, she stated,

“I have a transient population of students that are in crisis while learning from me... They come to me with varying amounts of background knowledge of science and the particular subject they are learning that year. They stay in my classroom any length of time from six weeks to more than one year... They range from general education to Other Health Impairment (OHI), Specific Learning Disabilities (SLD), Emotional and Behavioral Disorder (EBD), from juvenile justice custody to parental care, and from poverty to extreme wealth.”

The teacher emphasized that the school had a diverse student population, who stayed at school for a short period, and she had difficulty throughout the year in observing student improvement. Asia also indicated her challenge to get the entire group on the same page during the ADI activities as the students in her class studied different science subjects.

Asia addressed the influence of curriculum and testing in the implementation of ADI model. She stated,

“ADI prepares ... encourages them to think critically. EOCTs require more rote memory and fact recall, and they did not have as many questions that were situation-based. ADIs are a good way of preparing students for the test in the sense that you have to be able to read a question and understand the situation to see how it applies.”

This quotation suggested that ADI activities helped students develop content knowledge and study for the test through engaging in scientific practices including asking questions,

designing the investigation, data collection and analysis, and communicating the information in different ways rather than rote memorization. However, she had challenges related to the time necessary to complete an ADI activity as she always underestimated how long it took to complete an investigation.

Case-2: Bella

Bella had five-years teaching experience in physics, physical science, and psychology. She had a bachelor's degree in psychology. Bella was teaching in a Title-1 high school in an urban area located in the southeast region of USA involved 99.0% African-American students. During the study, she was teaching 10th-grade physical science classes involved at least 16 students, and one class period was limited to 90 minutes.

PCK of Argumentation

Table 15 included a summary of Bella's responses on three PCK of argumentation assessment. Her scores indicated a consistency in her knowledge of argument structure and dialogic process even though there was a slight decrease on the post1-assessment on both aspects. The detailed information about the change on Bella's PCK of argumentation throughout the study was provided below.

Argument Structure. Bella's pre- PCK of argumentation assessment scores indicated her limited knowledge of evidence conception, which was high-quality and consistent on post1- and post2- assessments and aligned with the informal conversations and final interview. During the PD program, she provided the appropriate definition of evidence and stated,

“Evidence is the information gathered from your investigation that supports your claim. The evidence is high-quality when it is quantitative. It also needs to include an interpretation sentence.”

During the informal conversations, she thought high-quality evidence involved both qualitative and quantitative data in making convincing scientific explanations. Her views aligned with her explanations during the final interview as she stated,

“I think the models would add support to anything... You use those either in your methodology or in your explanation of evidence...”

Bella’s pre-assessment scores indicated her high-quality knowledge of the reasoning conception, and she provided the appropriate definition of justification component during the PD reflections as the “*explanation of the evidence using scientific principles*” and evaluated the use of scientific principles as the strength of an argument. Her post1- and post2- assessment scores indicated a decrease showing her limited views on the reasoning conception by the end of the study as she did not sufficiently evaluate and support students’ responses on how the evidence connected to the claims.

Dialogic Process. Bella’s responses to three assessments and explanations during the project indicated her limited knowledge of student interactions as she did not sufficiently support students to convince others about the relevancy of their claim. For competing claims conception, even though she held high-quality views at the beginning of the study, she indicated limited views on the post1- and post2- assessments. However, her responses during the informal conversations and final interview represented her high-quality knowledge on competing claims. Bella evaluated and supported students in debating a topic with multiple claims and pushed students to think critically and do independent research. She also thought multiple perspectives might get students become confused and frustrated for not having a clear answer. On the dialogic process, Bella stated,

“It is important for them to realize that their opinions are valuable whether they are right or wrong. And they have to learn how to communicate with other people whether their answers

are right or wrong. So, you know, argumentation not only allows them to get a good grasp on the content, but it allows them to try to convince others of why they are right. And, so it helps with their interpersonal skills, but it also helps their depth of knowledge.”

The teacher addressed dialogic aspect as a way to develop students’ interpersonal skills, in which students could see the differences in each other’s ideas and defend their opinions based on evidence.

Knowledge of Student Conceptions. Bella indicated limited knowledge of student conceptions on both argument structure and dialogic process at the beginning, but she had high-quality knowledge during the PD reflections, informal conversations, and final interview. Bella thought students had difficulty in constructing sound arguments and stated,

“Students provided evidence that was not related to claim or students provided claim that was not related to evidence.”

Bella identified another challenge that students might provide personal experience or opinion as evidence. For the justification conception, towards the end of the study, Bella stated,

“The first step would be me teaching them explicitly how to conclude from written information, which is something they do not get a lot of experience with honestly.”

Bella emphasized students’ difficulty in using the academic language to integrate the scientific principles in explaining how evidence was connected to the claim.

Bella also addressed the dialogic aspect of argumentation, she stated,

“A lot of times they do not understand that their classmates have valuable information, so a lot of times, they just want to look for the teacher for the answer.”

She thought students had difficulty in understanding that their classmates might have valuable information; instead, they always focused on the right answers. She added,

“Giving and receiving feedback is a struggle for people, so if they start getting feedback and not taking it personally, but using it to inform themselves...”

Bella indicated students had difficulty in engaging in both internal and social debate in providing or receiving constructive feedback to inform their work rather than taking it as a personal attack. For competing claims conception, Bella addressed similar views on the student conceptions throughout the study. She thought to argue with alternative claims pushed students to think critically, but they might make students *“frustrated when they feel like there is not a clear answer.”* She added that students had difficulty in convincing others about the relevancy of their claims, and they might develop alternative ideas and could not use the proper scientific terminology during the discussions.

Knowledge of Instructional Strategies. Bella’s PCK of argumentation responses indicated her limited knowledge of instructional strategies for both structural and dialogic aspect of argumentation to address students’ challenges in this practice, which aligned with her suggestions during the PD reflections and informal conversations. For argument structure, the teacher suggested various scaffolding strategies such as modeling data collection and analysis and how to define the patterns within the data and using the rubric to develop high-quality arguments. Bella also considered using exemplars such as providing the examples of good and bad data sets or showing an example of a well-done essay and using graphic organizers or sentence starters including topic sentence or questions to answer piece by piece.

Referring to students’ low literacy skills, she stated,

“Forcing them to focus on the scientific language, using scientific language and using their resources because the justification ... supposed to come from the readings, from the background information, so ... ensuring that they are annotating the background information

and using it to design their experiment and then also to help analyze, using it in every step of the process ... will help them get better justifications.”

Bella mainly focused on building academic language through annotation strategies from the resources such as reading assignments to support students’ citing the evidence from the text to develop knowledge of science content. The teacher also endorsed the use of visuals such as videos or powerpoint presentation to teach the concepts and address the real-life applications of concepts.

Bella demonstrated similar knowledge of instructional strategies on the dialogic process. She suggested modeling how to provide feedback and providing conversation starter cards during the group-work activities to promote productive discussions. She added,

“In their Think-Pair-Share activities, they are at a table, and they each has to share their opinion and critique each other’s arguments that is the easiest, quickest way to get them engaged and discussing the topic at hand.”

She supported students in critiquing each other’s ideas, listening to and accepting each other’s feedback even they did not agree. She also thought to integrate hands-on activities, real-world phenomena, and combating issues to encourage students to argue for and against about a specific situation while working in groups.

Bella also indicated that students might have competing claims on the same issue, but they had difficulty in acknowledging each other’s ideas and stated,

“A lot of times they all want to be right, but they do not want to take on the other person’s opinion. So that, I think we need to not only figure out how to appropriately elicit good comments but also how to teach them how to interact and respond to each other’s comments as well is very important and sort of setting norms for that response.”

Bella thought prompting students to understand the value of their classmates' opinions and the significance of providing and responding to feedback from their peers. She also suggested showing different examples of the same phenomenon and providing two conflicting pieces of literature to ask students to debate and come to a consensus.

Knowledge of ADI Model. Bella described the ADI model as a structured process to help students internalize science and engineering practices as well as aspects of nature of science and develop critical thinking. She thought the model provided a context to design the investigation, collect and interpret data in the form of graphs, learn cross-cutting concepts such as patterns, develop arguments, and critique each other's work. She added that ADI model supported the development of literacy skills to be engaged readers, pull out the necessary information and learn the appropriate vocabulary and terminology.

Additionally, Bella discussed the specific stages of ADI model. She defined the *Identification of Task* as a stage to introduce the research question, the scientific concepts, and their real-life applications. The teacher suggested the explanation of the background information to guide the design of the experiment and data collection including both qualitative and quantitative data. She addressed the *Design of Investigation and Data Collection* stage as a process to teach students to be creative in determining the number of trials and sample size as well as characteristics of participants such as different age groups or grade levels to collect high-quality data. For *Argumentation Session*, she defined *Gallery Walk* as an opportunity to explore each group's methodology or design of investigation to see what other people were doing, share ideas with each other, critique and build off of each other's opinions, and define points to discuss during the explicit and reflection discussion session. For *Writing an Investigation Report* and *Peer Review* stages, Bella thought writing aspect of ADI as an opportunity to think about science and

scientific investigations and synthesize the information to develop literacy skills. She utilized the peer review rubric as a tool to explain the requirements of writing a paper.

Bella also addressed her challenges in implementing the ADI model. For the specific stages of ADI model, she was concerned about her questioning as she was used to providing the direct answers. She had difficulty in figuring out how to ask rigorous questions to extend students' thinking and support them in developing arguments. She added, *"My biggest struggle with teaching them how to collect data in an understandable way and what counts as data and what doesn't ... and interpreting data."* Bella addressed her difficulty in teaching how to collect data, make the connection between data and evidence, and generate justifications.

Epistemological Beliefs

Domain-General Beliefs. Table 16 presents the scores of *Epistemological Beliefs Survey* supported with participant's explanations during the informal conversations. Bella's domain-general epistemological beliefs mostly indicated her multiplist views about the nature of knowledge. She defined knowledge as uncertain and subjective products of individuals' opinions that have equal validity as she was unsure whether there were clear-cut answers to the problems even though people studied hard. She stated,

"You have to be open to hearing from others and taking others' perspectives. And if you are not, then it is not gonna contribute to the body of knowledge."

Bella thought people developed knowledge through hearing others' perspectives and engaging in different experiences to change their behavior. She indicated that two different people could have different opinions about the same phenomenon based on their own experiences, background, and biases, and they could use their existing knowledge to learn new things through different situations.

Bella held mixed views about controlling and influencing factors addressing her beliefs about nature of knowing; her responses were consistent on the survey and during the informal conversations. She indicated,

“People start learning from the second that they are born, and their motivation to learn helps them internalize the information. Learning also required hard work, repetition, and perseverance; teachers could create opportunities for students’ learning.”

She approached learning as both an innate ability and perseverance and thought that some students could understand things quickly, but all students could do well in school through working hard. For the process of knowing, Bella indicated mixed beliefs. She stated,

“People engaged in forming ideas by thinking through the process that they could develop a comprehensive view of a situation across the events or different experiences rather than memorizing the facts.”

First, the teacher held evaluativist views and defined learning as a gradual process and requiring original thinking. For the source of knowledge, she added,

“Knowledge people seek out knowledge that they already believe sometimes, like confirmation bias they seek out to confirm what they have already believe and it is much more rare that the opposite occurs. But, I would say, in today’s time, most people’s source of knowledge is the internet.”

Even though Bella thought the ideas of experts should be questioned, she defined the internet as the primary source of knowledge to encourage students to explore and access the information quickly through accumulated findings including opinion blocks, newspaper articles, websites, videos, and social media.

Domain-Specific Beliefs. Knowledge of NOS. The analysis of three implementations of VNOS-270 survey and final interview indicated that Bella demonstrated an improvement on some aspects of NOS. Table 17 presented the teacher's responses on three questionnaires. Bella consistently had mixed views on *creativity and imagination* and *subjectivity* aspects. For *subjectivity*, the teacher stated,

“Every scientist views information through their own lens that includes life experiences, biases, stereotypes, etc. Two scientists can interpret data sets in different ways.”

And, she thought scientists used their creativity and imagination in all aspects of investigation including planning the methodology of the study and discussing the implications.

The changes on Bella's views for some aspects of NOS occurred during the project. Her naive views about *the difference between observation and inference*, *empirical-embeddedness*, and *the difference between theory and law* aspects on the pre-survey shifted to mixed views by the end of the study. Referring to *empirical* aspect, at first, she thought scientific problems could be solved solely by using the quantitative data; but, on the final interview, she indicated,

“Science required a sound methodology that could be replicated and a process of asking and answering questions using qualitative and quantitative data to support or refute scientific explanations.”

Moreover, Bella's views on the *tentativeness* aspect shifted from mixed to naïve on the second survey, which changed to mixed views by the end of the study. She stated,

“Science was ever changing and growing... Existing body of scientific knowledge and applications might change as scientists interpreted the definitions based on new evidence.”

For *sociocultural* aspect of science, the teacher had mixed views at the beginning, which shifted to informed views by the end of the study. Her views on sociocultural aspect were linked to the subjectivity aspects of science as she stated,

“The interpretation of results was influenced by the cultural context and individual perspectives, which might influence scientific investigations depending on where people lived, who people talked to, and who people associate with.”

Beliefs about teaching and learning. Bella indicated her beliefs about indicators of learning through stating,

“Being able to explain in different ways, ... being able to explain it to a classmate is a good indicator, as well as, obviously passing in class exit tickets as an assessment..., but then also not only answering the questions but also asking questions shows a level of engagement that shows that there are some thinking and some learning is going on.”

She addressed students’ questions and explanations as well as the use of different types of assessments as the indicators of learning including clickers, exit tickets, and multiple-choice tests such as mathematical-based diagnostic. For her role as a teacher, she stated,

“In a perfect world, I would be a guide of information, but I have been more of dispenser ... but I just want my students to take more autonomy over their own learning and have more of an interest in it, whereas instead of kind of me forcing them to do something and give them steps and give them a procedure, I want them to be able to develop their own procedures by asking questions.”

Bella defined her role as both a facilitator or guide to encourage students to collaborate and figure out by themselves and develop higher-order thinking and the source of information through lecturing with the powerpoint presentation to teach the fundamental concepts and their

real-life applications. To maximize student learning, she supported integrating differentiated instruction to address all learning styles and stated,

“If you do need to do a lecture, because some topics do need the direct lecture, breaking it up, chunking it and giving them opportunities to either think-pair-share and groups or work independently and come back whole groups. Keeping it unexpected, as the tempo of the class, because they never know what is coming next.”

Bella addressed delivering the information in different ways including lecture-based instruction, group-work or individualized instruction to enhance student participation. Bella thought integrating simulations and hands-on experiments that could provide concrete experiences to communicate the information based on evidence. She also addressed the importance of the teacher-caring on students’ learning that a teacher could build a good relationship with students, translate the value of education and science, and motivate them to listen to each other and get to the next level of their learning.

Summary. Bella thought ADI model provided a context for students to experience how scientists worked and develop critical thinking and literacy skills such as being engaged readers and learning how to use the appropriate vocabulary. Bella’s pre-PCK of argumentation responses indicated that the teacher held limited knowledge of evidence, which became high-quality by the end of the study. The teacher could not maintain her high-quality knowledge of reasoning by the end of the study. Also, she indicated consistently limited conceptions of student interactions, high-quality conceptions on competing claims, and limited knowledge of instructional strategies, but her limited knowledge of student conceptions improved and was high-quality towards the end of the study.

Bella experienced improvements in her PCK of argumentation and epistemological beliefs by the end of the study. Her definition of characteristics of science was parallel to her

mixed views that science required a sound methodology of asking and answering questions using qualitative and quantitative data to support or refute scientific explanations. She thought ADI activities provided an opportunity to engage in argumentation through collaborating with peers, asking questions, sharing ideas, and giving feedback as each person might interpret a phenomenon differently in parallel to her knowledge of competing claims. Bella also thought she should act as a facilitator to enhance student learning through differentiated instruction including hands-on or collaboration activities to encourage students' participation in argumentation activities. She indicated that ADI investigations helped students critique and build on each other's ideas and develop interpersonal skills that aligned with her beliefs about nature of knowing as learning occurred in a gradual process; but was not directly related to her multiplist beliefs about nature of knowledge and her beliefs about nature of knowing as an innate ability and developed through accumulated resources. Bella's limited knowledge of reasoning and student interaction conceptions was parallel to her beliefs about her role as the source of the information. Her limited PCK of argumentation aligned with her multiplist beliefs about nature of knowledge as a process of individual meaning-making, beliefs about knowing as innate ability, utilizing the accumulated findings as the sources of knowledge, and beliefs about maximizing student learning through lecturing.

Teaching by Argumentation Instructional Model: Modified Enactment

Data collection around Bella's teaching practice included 14.5 hours of classroom observation to understand how her PCK of argumentation and epistemological beliefs translated into her practices. She had never done a complete ADI activity after the PD program; she could only implement the ADI activity in 1.5 hours related to *Memory and Stimuli* by making modifications without doing "Writing an Investigation Report," "Peer Review," "Resubmission

of the Paper” stages. Table 18 presents the type of the enactment and the implemented and observed ADI activities in one-year.

Her instruction included low-quality argumentation during the ADI activity related to *Memory and Stimuli*. She provided direct explanations about what students needed to do in specific stages of the model. For example, while reading the text related to the ADI activity, she prompted students to annotate, circle, and underline the words or phrases to support them in citing evidence from the text aligning with her limited knowledge of instructional strategies. And, she promoted *Triadic Dialogue* to support students in the design of the investigation and data collection and analysis, particularly, to consider the difference between qualitative and quantitative data.

Bella addressed the definitions of the structural elements of an argument during the “*Development of a Tentative Argument*” stage. She guided students in developing the evidence from raw data and stated,

“Think about, when you make data, you want to organize in some form of... If you have quantitative data, you might organize the data, so it becomes nice and easy to read... Chart, table.”

Then, she elaborated on her explanation and defined the evidence and justification as,

“Your evidence is your data, and how you interpret that data. Justification ... is ... to link your evidence to your claim...”

Her definition was parallel to her high-quality knowledge of evidence conception and limited understanding of justification conception. And, she emphasized students’ difficulty in justification as the hardest part of an argument in parallel to her knowledge of student conceptions. Bella’s practices also aligned with her beliefs about her role as a teacher as she preferred directly explaining the definition of the structural components of an argument.

Additionally, Bella integrated group work and whole class discussions in parallel to her knowledge of the dialogic process. She rarely promoted student interaction through encouraging students to work collaboratively, which was also parallel to her domain-general epistemological beliefs that knowledge was uncertain and subjective, and learning occurred in a gradual process. The teacher addressed her mixed views about empirical-embeddedness of science while students were working on the design of investigation and data collection, she stated,

“How long does it take for him to remember the phase? Or how many letters he got correct? Those are all examples of data that show or help you answer the guiding question... you need to do chart, table, and more than one trial.”

The teacher encouraged students to do more trials, determine the patterns, and organize the data in some form of charts and tables by referring to the scientific processes.

Bella combined the *Argumentation Session* and *Explicit and Reflective Discussion* stages in the form of a whole-class discussion to address students’ alternative ideas. She stated,

“Next year they have all new standards for all science, ... you are ... investigating and coming up with your own claims that we come back, talk about to make sure everyone is on the same page that the concept is right... Everyone has the same question... We would actually go around and share each of our procedures. ... You see that everybody tries to answer this question in different ways, so I want everyone to read their claims...”

Bella discussed that standards supported the implementation of ADI model. Even though she integrated group presentation format to encourage students to share their arguments with the whole class, the teacher did not help students critique each other’s work and reflect on the strengths and weaknesses of their investigation that was not parallel to her knowledge of competing claims.

Bella's practices mostly aligned with traditional instruction in parallel to her beliefs about her role as the source of information and maximizing student learning. Bella lectured with work-out problems, clickers, demonstrations, and pre-made visuals such as powerpoint presentation and videos and assessed students' learning through fill in the blank, matching definitions, and multiple-choice questions. She also integrated the scaffolding strategies such as modeling how to explain, providing sample solution and sentence starters and individualized instruction through *Station teaching* focusing on the areas that students needed improvement that the teacher clarified the task and guided students towards answering the question. She rarely promoted student interaction through supporting collaboration among peers through asking questions, sharing and discussing their ideas in parallel to her limited knowledge of student interaction throughout the study.

Factors Influencing the Argumentation Instruction

Bella talked about various factors influencing the implementation of ADI model. She addressed her beliefs about students' abilities and indicated that students used to do cookbook type of labs with deliberate steps, and she stated,

“They had zero experience with gathering and interpreting data... After doing ... two investigations, really changed my thinking in terms of they can do this.”

She added,

“They have become used to just defending their answer without me even asking. They still need more practice writing.”

She indicated that students improved their ability in asking and answering the scientific questions and collecting and interpreting the data as evidence to support their claims and defend their arguments. Bella also addressed her beliefs about prior knowledge and stated,

“They know the math, but they do not know what they are calculating... You would be surprised by how many of them don’t know what analyze means, or compare or contrast, or summarize.”

Bella referred to students’ difficulty in understanding their calculations and their weak reading and writing skills as barriers to their learning through argumentation.

The teacher also believed that students’ attitudes such as attendance, behavior problems, and motivation as barriers to their engagement in argumentation activities. She added,

“Their motivation to just understand anything is low; they are so much focused on getting a grade.”

The teacher emphasized the unique aspects of urban schools including students, who were underachieving and dealing with poverty issues. Besides student ability, Bella indicated that district determined the standards and stated,

“New standards start with obtain, analyze, and communicate information, and I think just even putting those words in the standards is goanna make it a lot more natural for us to use argumentation daily.”

She thought standards addressed science and engineering practices, nature of science, and crosscutting concepts that were naturally embedded into ADI investigations. However, she discussed the challenge that the teachers were pushed by the district to teach for the test. They did not have flexibility over the curriculum, and lack of resources and time were the barriers to performing the complete ADI investigations. Additionally, Bella talked about the professional learning community including physical science teachers in her school as a barrier to teach scientific argumentation as instructional coach pushed teachers to follow the similar lesson planning and utilize the same resources.

Case-3: Eva

Eva was a veteran teacher with 26 years teaching experience in science disciplines including biology, chemistry, physics, physical science, environmental science, and forensic science. Eva had a bachelor's degree in biology and master certificate in secondary science education; she was also a specialist for educational leadership. Eva was teaching in a Title-1 middle school in an urban district in the southeast region of United States; the majority of students were African-American (99%), and there were also Hispanic students at the school. At the time of the study, the teacher was teaching 8th-grade physical science classes including at least 25 students, and one class period was limited to 50 minutes.

PCK of Argumentation

Table 15 presented a summary of Eva's PCK of argumentation assessment responses. Eva completed the post1-survey taken at the end of the PD program and post2-survey after one-year implementation of ADI model. She did not provide any response on pre-survey; so, the data for her PCK of argumentation at the beginning of the study was collected through the reflections during the PD program. Her score indicated an increase in her knowledge of structural elements, but a decrease related to the dialogic aspect of argumentation. The detailed information about the change on Eva's PCK of argumentation was provided below.

Argument Structure. Eva provided accurate views of evidence conception even though her knowledge of reasoning was limited at the beginning of the study. She defined argumentation as,

“The investigation issue, form a question; then collect empirical evidence of your hypothesis based on scientific principles and justify your position.”

During the informal conversations, she thought evidence as the qualitative and quantitative data to explain a claim, which could be represented in the form of video, interview, electronic

software, charts, tables, and graphs. Then, she defined reasoning as, “*general standpoint of a phenomenon using theory and laws.*” She emphasized the use of scientific principles to address an issue; however, her definition didn’t explain the significance of linking evidence to claim to tie back to the science concepts.

Eva indicated limited knowledge of evidence and reasoning conceptions on the post1- and post2- PCK of argumentation assessments. The teacher did not provide sufficient knowledge while evaluating students’ responses whether they provided evidence to support the claim and whether they explained why evidence supported the claim by using the scientific principles. However, during the informal conversations and on the final interview, Eva provided the accurate definition of evidence and reasoning conceptions. She linked the evidence to justification and stated,

“Include the interpretation of the analysis, including the analysis of data... and ... on the justification, explain why this evidence was.”

And, she elaborated on her definition of justification as,

“The explanation of why the evidence supported the claim using the concept of theory and academic vocabulary.”

By the end of the study, Eva indicated high-quality definitions of evidence conception as the analysis of data organized in the form of a chart, table, graph, or diagram and justification conception as the explanation of why the evidence supports the claim that could be tied back to the scientific concepts with appropriate academic vocabulary.

Dialogic Process. Eva’s responses during the PD program and on the PCK of argumentation assessments indicated her limited knowledge on the dialogic aspect of

argumentation; however, she provided high-quality understanding during the informal conversations and final interview. For example, on student interactions, Eva stated,

“I have had really students to delve into it and think that my claim is right or wrong. I led them simply argue it out. They can state their evidence and justify, argue it out. I listen to them, go back and forth and talk about what they did and why.”

She thought argumentation naturally occurred during the collaborative activities as students listened to each other, exchanged their ideas, and convinced each other for the strength of their claim through using the academic vocabulary and making connections to real-life applications. For competing claims, she indicated that argumentation involved both internal and external thinking that individuals engaged in thoughtful and persuasive conversations about multiple perspectives, which they brought into the discussion.

Knowledge of Student Conceptions. The teacher had inaccurate knowledge of student conceptions on the PCK of argumentation assessments, but she indicated high-quality understanding to evaluate students’ strengths and weaknesses in engaging in the process of scientific argumentation during the informal conversations. Eva thought students had difficulty in constructing sound arguments and stated,

“Evidence should be on the chart; it should be a graph, it should be a table. And they don’t get to write that evidence before they even research until they know what kind of chart or table. They need to answer those three questions first. How do they collect data, what type of data will they collect, why you gonna collect data? Once they answer those questions, they can collect the evidence easily.”

Eva indicated students provided insufficient evidence to support their claims, and they needed to improve data collection process through considering,

“How do they collect data, what type of data will they collect, why you gonna collect data?”

She added,

“They can collect and look at and see; what is good evidence and bad evidence ... They have very accurate data, and others have data is everywhere, that requires more trial.”

The teacher indicated that students needed to improve the quality of evidence through collecting multiple data in several trials to identify what bad and good evidence was. Eva also addressed students’ challenges in developing sound justifications. She stated,

“They are not using the scientific terminology, they are not using the concept into the explanation, into the justification, into whatever their writing.”

She thought students needed to learn the academic vocabulary and build knowledge of fundamental concepts to understand the research question, figuring out the design of the investigation, data collection, and analysis to improve the quality of evidence and justifications in their arguments. Furthermore, Eva addressed students’ challenges during the dialogic process. She thought students were used to focus on the correct answer and get grades for completion, so they developed alternative conceptions of science concepts that led to having difficulties in staying engaged in academic conversations. She also referred to students’ difficulty in listening to their peers while discussing competing ideas.

Knowledge of Instructional Strategies. The strategies that Eva provided on the PCK of argumentation assessments and during the informal conversations reflected her limited knowledge of both argument structure and dialogic process, which were not able to support students to engage in argumentation in-depth. For example, Eva suggested scaffolding strategies such as modeling data collection and analysis, using the posters and charts on the wall including the critical vocabulary and sentence starters to promote students’ use of argument structure. In particular, the teacher considered

preparing a *Think-sheet* to scaffold the ADI process, which included questions related to the concept of the activity and guidance about the design of the investigation. She stated,

“The Think sheets tell them to cite the evidence for why you are thinking this. Cite the evidence for this definition ... They have to learn how to cite, they have to go into the reading, and cite the evidence on the Think sheet.”

The teacher thought to prompt students to highlight, underline, and circle the conceptual vocabulary to learn how to use them in sentences and develop academic vocabulary and sound arguments. She added,

“I would do the vocabulary cards, words on one side and the definition on the other, you just got a card and tried to make sure these words were included in your conversation and included in your writing... I need to see the certain number of these words underline where these words.”

Eva suggested providing the list of the words or conversation starter cards related to the ADI activity to scaffold students’ scientific writing and discussions. She also addressed the use of “*think-pair-share*” activity and specific grouping strategies such as putting “*the strong thinker with the strong writer*” to promote the student interaction.

PCK of argumentation assessment responses indicated that Eva considered supporting students’ competing claims through “*showing a video of a scientist questioning another scientist’s claim.*” She elaborated on this strategy during the informal conversations and stated,

“They need a little lecture where I make the powerpoint and just have the words and pictures attached to the words, they need that, so I try to meet a lot of learning styles and in a mixed population and cover some misconceptions.”

Eva addressed the necessity of doing direct instruction through integrating visual sources such as animations, simulations, demonstrations, and powerpoint presentations to help students

learn science concepts. She also thought using these resources to elicit students' ideas and provide examples from real-life implications of concepts to hit different learning styles and address their alternative conceptions. Eva emphasized the significance of promoting students' metacognitive thinking through supporting their reflections on what to do differently for their learning and modeling the reflections.

Knowledge of ADI Model. Eva described ADI model as an opportunity to engage in both structural and dialogic aspects of argumentation including discovering, collecting, and organizing data, and communicating back to the background information through reading, writing, and having academic conversations. She explained the process as,

“Not only labs, following through with having the purpose, hypothesis, going through pull the materials, design the experiment, doing the experiment, capturing the data, make an analysis of the data, and then coming back and writing the conclusion regarding that data, and assessing it, and rewriting the conclusion. And going back through the entire lab, and assessing what was done, and see how you can do it better.”

She thought that ADI model naturally incorporated scientific practices to help students think critically, form evidence-based explanations, and experience the frustration of science.

Eva talked about specific stages of the ADI model with some variations. She defined the *Identification of Task* stage as including reading tasks to develop the knowledge of science content. The teacher addressed the “*Development of a Method and Data Collection*” and “*Data Analysis and Development of an Argument*” stages for the development of the structural elements of an argument. She indicated that students had the autonomy to figure out the design of the investigation, engage in accurate and precise data collection, and put the data in charts, tables, graphs, or diagrams to support a claim and demonstrate the connection between claim and evidence.

Moreover, Eva described the “*Writing an Investigation Report*” phase as a vocabulary contract as she evaluated students’ writing to determine whether they utilized the list of the words. She also indicated that ADI model provided an opportunity to engage in reflective and persuasive writing through answering three questions: What questions are you trying to answer and why? What did you do to answer your questions and why? What is your argument? For the *Argumentation Session*, the teacher referred to the *Gallery Walk* as a way to look at each other’s work to provide feedback and revise their arguments. She defined the *Explicit and Reflective Discussion* stage as a whole-class discussion, in which the teacher promoted discussions about what students have done as well as aspects of nature of science and cross-cutting concepts. She thought that the *Gallery Walk* and *Peer Review* stages were the most challenging part of ADI in a crowded classroom.

Epistemological Beliefs

Domain-General Beliefs. Table 16 presented Eva’s responses of *EBS*. Eva had multiplist views indicating knowledge as depending on personal experience that could have either discrete pieces or be complex. There was a consistency between survey results and her explanations during the informal conversations and final interview. She thought that the information should be presented as simple as possible to be understandable for students. However, Eva also stated that knowledge involved multiple layers of information and could be complicated and interrelated; so that scientists might reach the scientific facts through working hard for an extended period.

For controlling factors, Eva held mixed views and defined learning as both an innate ability as well as perseverance and hard work. Referring to the learning as an innate ability, she stated,

“It is an innate, survival is innate... Those teachers who stay, work on lesson plans, and look at students and look at test scores, and write lessons, they enough have better students, they produce better students, they become better teachers... Absolutely the same way, there are

some innate things, but they are based on the survival... Some of most brilliant people never reach their capacity, they never maximize their capacity for learning... They do not have the intrinsic desire to learn more, but they are brilliant.”

Then, she emphasized the hard work and stated,

“Efforts are reflected throughout with their understanding if they show consistent effort. If they show consistent effort, they are going to be producers... Effort needs to be sustainable.”

She added that being a good student did not involve memorizing lots of facts; students might not be able to understand the main ideas easily and might need to show sustainable effort.

For the process of knowing, Eva held mixed views and thought that knowledge was uncertain, subject to change; and people needed to make evidence-based explanations informed through the scientific process rather than directly receiving the information from the teacher or the textbook. During the informal conversations, she suggested the experience and accumulated findings as the sources of knowledge. She stated, *“Experience plays a big part of learning”*; specifically, reading books and online resources, going different places, and interacting with other people give experiences to learn more.

Domain-Specific Beliefs. *Knowledge of NOS.* The analysis of three implementations of VNOS-270 survey and final interview indicated that Eva experienced slight changes in her understanding of some aspects of NOS. Table 17 presented Eva’s responses on three VNOS-270 questionnaires. She did not change her views on *“subjectivity, the difference between theory and law, the difference between observation and inference, and sociocultural”* aspects of NOS across three surveys. Eva indicated mixed views on *“subjectivity and the difference between theory and law”* aspects. She consistently referred to differences in personal understanding, experience, background, and beliefs to conclude. The teacher defined *“scientific theories”* as propositions formulated to

explain a group of facts or phenomena in the natural world and repeatedly confirmed, whereas “*scientific laws*” as a generalized rule to explain a body of observations and cause-and-effect relationship in the form of a verbal or mathematical statement.

Additionally, she had naïve views on “*sociocultural and the difference between observation and inference*” aspects of three survey responses. She was unsure whether culture influenced the development of scientific knowledge, and she could not accurately define *the difference between observation and inference*, but during the informal conversations, she had more accurate views and defined *observation* as dealing with the senses and *inference* as differences on interpreting the same phenomena.

Besides, Eva’s views on “*creativity and imagination, empirical-embeddedness, and tentativeness*” aspects changed during the project, shifting from naïve to mixed views as she thought scientists used their creativity and imagination in all parts of the investigations. Eva also indicated that different stories could be written with the same set of words based on the author’s creativity and imagination. Moreover, her views about *empirical-embeddedness* aspect decreased from mixed to naïve by the end of the study. Though her views about *tentativeness* aspect increased from mixed to informed, following the summer experience, her views again decreased to mixed views at the end of the study; and she linked the *empirical-embeddedness* to *tentativeness* and stated that new evidence led to refute theories and develop new ones as science was ever-evolving.

Beliefs about teaching and learning. Eva believed that students understood the concepts when they collaborated with their peers or by looking at their explanations and interpretations. Regarding understanding science concepts, she thought generating and answering the questions, making connections between science concepts, and applying them to real-life situations were indicators of learning. Eva also stated, “*If they can answer the questions on the assessment ...*

they can understand the concept.” She thought exit tickets and rubrics as the ways to evaluate students’ learning.

Eva represented mixed beliefs about her role as a teacher. First, she defined her role as the sole source of the knowledge, who covered the fundamental concepts and their real-life applications that students needed to master. She indicated,

“I have been modeling how to solve problems, demonstrating the phenomena, and teaching the etymology of words to teach what students needed to know.”

Second, she defined her role as a guide during the ADI activities to encourage students to collaborate and figure out by themselves and develop higher-order thinking.

To maximize science learning, the teacher thought that she should give students opportunity to discover, make connections to real-world phenomena, and change the instruction based on research. She added that she should also lecture, and stated,

“They need a little lecture where I do the powerpoint and just have the words and pictures attached to the words, they need that, so I try to meet a lot of learning styles and in a mixed population and cover some misconceptions...”

Besides teaching the concepts, she also thought to explain the metacognitive thinking and addressed teaching the classroom rules, matriculation procedures, and teacher expectations to enhance students’ learning.

Summary. Eva indicated that ADI model was embedded into the standards that the phases of the model could be integrated into any instructional framework such as project-based or problem-based learning. Her responses on the PCK of argumentation assessments indicated her limited views on both structural elements and dialogic aspect of argumentation, but the informal conversations and final interview demonstrated her high-quality knowledge on these conceptions.

Eva held limited knowledge of instructional strategies for argumentation that could not promote argumentation in-detail, but her limited knowledge of student conceptions improved and became high-quality by the end of the study.

There was a consistency between Eva's PCK of argumentation and epistemological beliefs. Eva believed knowledge as constructed in different ways depending on the personal experience and supported both the research-based and teacher-centered instruction to maximize student learning. She believed that traditional instruction was effective to develop scientific knowledge in parallel to her approach to knowing as an innate ability, using accumulated findings, and her role as the source of information. However, she defined science as a systematic process required creativity and imagination from planning to communicating the results that might change based on new evidence. She supported acting as a facilitator during the ADI activities in parallel to beliefs about knowing as a gradual process to enhance students' active involvement and engagement in the design of the experiments, data collection and analysis, debate, and metacognitive thinking. She experienced a slight shift on her knowledge of NOS; her naïve and mixed views on the aspects of NOS linked to her limited knowledge of instructional strategies for argumentation that did not address nature of science as embedded into argumentation activities. Her multiplist beliefs about nature of knowledge, mixed beliefs about controlling factors and teaching and learning science were aligned with her beliefs about the source of knowledge as including both experience and accumulated findings such as a textbook.

Teaching by Argumentation Instructional Model: Modified Enactment

Data collection around Eva's teaching practice included 18 hours of classroom observation to understand how the teacher's PCK of argumentation and epistemological beliefs were translated into her practices. During the classroom observations, the teacher implemented two ADI activities at the

same time; half of the students worked on an investigation related to magnetic force, and the other half of the students worked on one related to electricity. She addressed all stages of the model in her implementation except “*Stage 7: Double-Blind Peer Groups Review*” and “*Stage 8: Revision and Submission of the Investigation Report*” stages. Table 18 presents type of the enactment and the implemented and observed ADI activities in each teacher’s classroom in one-year.

Eva modified the ADI model based on her knowledge and beliefs to cover the content. Her classroom practice during the “*Identification of Task*” stage focused on explicit instruction to explain the science content through using a powerpoint presentation and called this instruction as part of ADI model even though she did not directly use the resources provided by the PD program. Her practices aligned with her epistemological beliefs including her beliefs about teaching and learning and about nature of knowledge that the teacher acted as the sole source of information through lecturing to build the background knowledge and provided examples from daily life. Eva’s display and rhetorical questions promoted competing claims during the explicit instruction in the form of “*Triadic Dialogue*” to address the science concepts and NOS including *tentativeness, subjective, and empirical-embedded* aspects. Her definition of these NOS concepts during the classroom instruction aligned with her domain-specific epistemological beliefs. For example, she stated,

Teacher: What does it mean to be empirical? It says based on the empirical results. It has to be with numbers. If you have results, they are not just subjective, but they are calculated based on numbers. We can calculate current and get an empirical result... What can we get with the light bulb? Watts, isn't it empirical? Empirical must be calculated.

Student1: Anything with numbers in science called empirical?

Teacher: Yes, it has to do with numbers. That is the point that I am trying to make... Empirical, it has to do with numbers. Two things the fact that it is empirical. Empirical evidence tells us that

at some point it can be calculated, but it is also sometimes that we do goanna have something in design and experiment. What would be empirical? What would have a number? ...

In this quotation, Eva presented naïve views on the empirical-embeddedness of science as objective based on calculations, not involving qualitative information, and collected through design and experiment. She demonstrated mixed views on the tentativeness of science as changing and evolving. However, she did not emphasize “*the difference between data and evidence and between theories and laws*” related to two ADI activities. In parallel to her beliefs about science learning, she assessed students’ learning with quizzes and utilized the rubric to evaluate students’ use of argument structure. She also utilized the textbook and online resources as the source of learning in parallel to her beliefs about knowing as learning was an innate ability and occurred quickly.

In other stages, Eva supported students to collaborate with their peers to develop knowledge in a complex process in parallel to her high-quality understanding of the dialogic process. The teacher promoted student interaction, but rarely addressed students’ alternative ideas to critique each other’s claims and build off of their ideas. For example, Eva distributed a “*Think-sheet*” as a guide to promote students’ thinking about the research question and the background information and decide how to design the experiment and collect data as a group. Additionally, Eva modified the implementation of ADI model through combining “*Argumentation Session*” and “*Explicit and Reflective Discussion*” stages. The teacher prompted students to evaluate the strengths and weaknesses of their posters by using the modified version of the peer review rubric. The modified rubric scaffolded the review process through questions such as,

“Is the claim sufficient, does the poster include data, analysis of data, and interpretation of analysis, does the author explain why the evidence is linked to an appropriate concept?”

For the “*Explicit and Reflective Discussion*” stage, the teacher met each group separately to talk about what students have done, why they have done, and what they needed to do next time to improve data collection and analysis as well as the design of the investigation. Though, she did not encourage students to discuss the aspects of NOS related to the investigation.

Eva addressed the use of argument structure during the “*Development of a Tentative Argument*” that she defined the structural elements of an argument and suggested students consider the research question on each stage of the investigation to write sound arguments. In parallel to students’ difficulty in developing sound justifications, she gave priority to explain why the evidence was important and relevant by using appropriate scientific terms. During the “*Writing an Investigation Report*” stage, she also provided the sentence starters on a poster including “*Evidence shows that ..., the author wrote ..., an example is ..., I know this because ..., and the data shows.*”

Eva’s use of argument structure aligned with her knowledge of student conceptions and instructional strategies. Her integration of the argument structure did not align with her multiplist beliefs about knowledge as uncertain and subjective that each opinion had equal validity and did not require any criteria related to empirical evidence.

Factors Influencing the Argumentation Instruction

Eva attributed limited implementation of ADI model to various factors. She believed that students’ abilities were one of the main factors for the teacher to integrate argumentation into science instruction. She thought students improved their ability in collecting data through multiple measurements and trials, developing thorough arguments and complex sentences to include in their poster as well as investigation reports. However, they had poor reading and writing abilities as a barrier to engage in scientific argumentation. For example, she said, “*Students’ lack of reading ability was a problem to read and answer the questions.*”

Another factor that the teacher believed in influencing the implementation was related to students' attitudes. She stated, *"These kids do not have best study habits."* Eva thought students had lack study habits and motivation to learn the science content, and they had lack of resources or were irresponsible to bring the supplies to the school. She added, *"I do focus on small groups because of the behavior, because of the attention span, because of the maturity."*

The teacher modified the ADI model to integrate more small group activities to monitor students' learning due to students' behavior issues and differentiate her instruction for different groups, including English for Speakers of Other Languages (ESOL) or gifted students.

Eva also discussed the factors influencing the implementation of ADI model besides students' ability. She thought, *"ADI is district initiative"* as district supported the implementation of ADI model, which was aligned with the standards and naturally provided an inclusive process to integrate the best practices into science instruction including investigation, research, writing, and peer review. The teacher approached the implementation of ADI model as advantageous to prepare students for the test, but time was the premium factor, and ADI activities could take more than five days (sometimes eight days). She thought students might need more time and resources to learn how to discover, be systematic about doing science, and build background knowledge about concepts to develop sound arguments.

Referring to the school context, Eva thought that the school administration was supportive of using the ADI model, but she addressed the other barriers within the school context. Eva indicated,

"We need more content teachers in the after-school program ... in the school day because most of the teachers, who run the program, are not content teachers."

She thought collaboration activities also influenced the argumentation instruction; for instance, she needed to collaborate with English Language Arts (ELA) teacher to improve

students' argumentative writing during the ADI activities. Specific to classroom context, Eva thought that middle school classes were crowded and limited to 50-minutes, and there was so much interruption related to extracurricular events that made the implementation of ADI model difficult.

Case-4: Olivia

Olivia had five-years teaching experience in physics, physical science, and anatomy subjects. She had bachelor degrees in biology, sociology, and psychology and a master degree in science education. Olivia was teaching in a Title-1 high school in an urban area located in the southeast region of USA involved 99% African-American students. At the time of the study, she was teaching 12th-grade anatomy class involved pre-college students, class size ranged from six to 10 students, and each lesson was limited to 90 minutes.

PCK of Argumentation

Table 15 presented a summary of Olivia's PCK of argumentation assessment scores. Olivia only took the pre-assessment, which indicated her high-quality views of structural and dialogic aspects of argumentation with limited knowledge of student conceptions and instructional strategies. The PD reflections, informal conversations, and final interview demonstrated the change in Olivia's PCK of argumentation. The detailed information about the change on Olivia's PCK of argumentation during the project was provided below.

Argument Structure. Olivia's pre- PCK of argumentation assessment scores indicated her high-quality knowledge of the evidence conception, which were consistent with her views by the end of the study. During the PD program, she made the distinction between data and evidence explicit and defined data as, *"gathered from investigations or research. This data can be quantitative or qualitative, but it should address the driving question posed to the class,"* and evidence as *"used to support a claim ... based on value, experience or data."* During the informal

conversations and final interview, Olivia elaborated on and defined evidence as the interpretation of data that needed to be relevant to the research question and comprehensive to be high-quality.

Olivia's pre-assessment responses indicated her high-quality knowledge of reasoning conception as well, which aligned with her explanations during the PD program, informal conversations, and final interview. During the final interview, she defined reasoning as,

“Explaining the evidence that they gather and relate to the claim that they are making in order to solve our answers and question that we are working on guiding question.”

She consistently defined reasoning conception as the explanation of how evidence was related to the claim and the research question that required incorporating the scientific concepts to connect evidence with the claim.

Dialogic Process. Olivia's responses on the PCK of argumentation assessment indicated her high-quality knowledge of the dialogic process, which was supported by her explanations throughout the project. Olivia defined argumentation as, *“a process through which students engage in a social experience”* to convince each other about the relevancy of their claims while doing science collaboratively with their peers. During the final interview, the teacher stated,

“Students are learning how to take different sides to the same issue, and they are learning to gather evidence..., so learning how to gather that evidence so how to present it in a way that is compelling, and it has to more ways to explain that observation and natural phenomena.”

She thought argumentation activities supported students to share multiple perspectives on the same issue, listen to each other, receive feedback, and make revisions based on the peers' comments.

Knowledge of Student Conceptions. Olivia's pre-assessment responses and reflections during the PD program indicated her limited knowledge of student conceptions, but she demonstrated improvements towards the end of the study on both structural elements of an argument

as well as the dialogic process. She addressed students' challenges, learning goals, and the strengths and weaknesses in the use of argumentation during the project. The teacher thought students had difficulties in "*making that distinction between ... the accurate claim and inaccurate claim*" as well as in providing high-quality evidence and using personal opinions or scientific principles as evidence.

Olivia also addressed students' challenges in understanding justification conception, and she stated,

"Justification part, they were still very confused about... Some of them used tables for their justification where I may have been looking them to explain what they put in the evidence and how their evidence supported their claim."

The teacher thought they could not explain why the evidence supported the claim and suggested that students needed to develop scientific knowledge to make sound arguments, specifically sound justification in their writing.

Olivia had inaccurate views of the student conceptions of dialogic aspect at the beginning of the study as she was not able to identify the benefits or drawbacks of having students debate a topic with multiple claims. However, during the informal conversations, she provided her learning goals and stated,

"I try to get them to discuss among each other, share their ideas... Some of them have misconceptions that they oftentimes correct each other."

Olivia elaborated on her explanations on the final interview and addressed students' difficulty in communicating their ideas and evaluating the accuracy of others' claims without directly accepting them. She thought students might have multiple perspectives on a natural phenomenon and having group discussions helped students revise their alternative conceptions.

Knowledge of Instructional Strategies. Olivia's pre-assessment responses indicated her limited knowledge of instructional strategies for argumentation, which were consistent with the strategies that she proposed during the informal conversations and final interview. She suggested scaffolding the development of an argument through exemplars, graphic organizers, and rubric. She reported how she had used the Claim-Evidence-Reasoning (CER) framework and stated,

"I show a video, and I stop it, say, 'make a claim.' And then, I stop it, 'jot down the evidence that you collected.' Watch the experiment on the video, actually record the data... And, they have them sort of justification for their claims based on the evidence that they collected."

She also considered teaching how to cite the evidence from the literature, using the visual sources, and integrating different levels of reading tasks to improve the quality of arguments.

On the dialogic aspect, Olivia suggested integrating think-pair-share activities, discrepant events, and conversation cards to promote discussions. On the final interview, she elaborated on the previous explanations and stated,

"I might walk around and ask probing questions and remind them to look at from multiple angles or push them to... support with different types of evidence... to re-strengthen their argument."

She thought group work activities might help students think through open-ended questions, see multiple perspectives rather than using personal opinion to critique and evaluate the relevance of each other's claims.

Knowledge of ADI Model. Olivia defined ADI activities as different from cookbook type labs and as prepared from a constructivist standpoint to learn how to ask questions, design the investigation, make observations, collect and analyze data, and develop the arguments. She stated,

"ADI is very independent and student-centered ... that they were able to come to these conclusions based on that evidence that they collected."

Olivia thought the ADI model promoted a social and authentic scientific experience through sharing ideas and learning from each other, and she added that students had an opportunity to learn the characteristics of science through ADI investigations.

Olivia also talked about the specific stages of ADI model. She thought she needed to explain all the materials related to ADI investigation during the *Identification of Task* stage and to address the use of investigation proposal during the *Design of Investigation* stage. For the *Explicit and Reflective Discussion* stage, she stated,

“They just talk about. What we are gonna do, would we all find, what was the difference between, the poster we go around, what do you think you should have. What conclusions should you make.”

She addressed this stage as an opportunity to talk about what students found, what they included on the poster, what conclusions they made, and how they might revise their work.

For the *Argumentation Session* stage, she defined the *Gallery walk* as a process of going around while one person stayed with the board to share ideas and learn and discuss with other groups. For *Writing an Investigation Report* and *Peer Review* stages, she thought investigation reports should address three questions as, “*What did you do? Why did you conduct the investigation in the way you did? What is your argument?*” She added that *Peer Review* process provided the opportunity to communicate the information and compare the results at a professional level. ADI model provided peer review rubric as a guide to include background information, sound methodology, and structural elements of arguments in writing the reports. Olivia had challenges in the implementation of ADI instructional model. She stated, “*ADI requires a lot of understanding on my part of the steps, but, which I need to become more familiar with.*” She addressed her difficulties in understanding and defining the role of the specific stages of the model and implementing them with fidelity.

Epistemological Beliefs

Domain-general Beliefs. Table 16 presented the Olivia's responses on *Epistemological Beliefs Survey*, which indicated her multiplist views on her beliefs about nature of knowledge aligned with her explanations during the informal conversations. She approached knowledge as uncertain as she was unsure whether scientists could get the right answers through working hard. During the informal conversations, she stated,

"Knowledge can be co-constructed. The more we work together, the more we rely on the work done from others... that is how we build the knowledge base."

She addressed knowledge as constructed through integrating and synthesizing multiple perspectives and added that people might interpret the same issue differently based on their subjectivity, and they might not find the truth even though they worked for an extended period. She criticized the information in the textbooks as simple and the school system as focusing on the objective truth through defining the knowledge as the mastery of state standards.

On the beliefs about nature of knowing, Olivia indicated her mixed views about the process of knowing even though she held evaluativist beliefs about controlling and influencing factors as requiring sustainable effort. She stated,

"Learning can occur over time with effort... I push them to look things up, a lot of time, I do not give them an answer... I am pushing them to research to cite their sources, look for credible sources, look for research to support the answers that you are trying to get for your questions, pushing them to always do that."

Olivia thought learning occurred in a gradual process through consistent effort including doing research and interacting with others and the natural phenomena rather than getting the work done quickly. For the sources of learning, she indicated textbooks and encyclopedias to find reading

passages, review the vocabulary, and develop background knowledge as well as the internet to do research and gather information.

Domain-specific Beliefs. Knowledge of NOS. Olivia's views on the aspects of science were evaluated based on her responses on the pre- and post2- VNOS-270 questionnaires, informal conversations, and final interview. The results related to the teacher's knowledge of specific aspects of science were presented in Table 17. Her scores were consistent across the pre- and post2- questionnaires. She consistently held mixed views on all of the aspects of NOS except "*the difference between theory and law and sociocultural*" aspects.

Olivia linked the *empirical-embeddedness to creativity and imagination* aspect of science, and stated,

"Creativity and imagination are essential to scientists who seek to ask novel questions, design scientific experiments to solve problems and answer questions."

Referring to the *subjectivity* aspect, she added,

"Many different scientists ... are specializing in different subjects ... It gives the multiple perspectives on the same natural phenomena."

The teacher thought scientists interpreted the same phenomena from their perspective and background, which might cause the explanations to change in science in parallel to her views about tentativeness aspect of science.

On the *difference between observation and inference*, Olivia provided appropriate definitions and indicated,

"Observation is that ... you can detect with your senses... Inferences are the sort of guesses that you make based on your observations about maybe what could be happening."

Her views on *the difference between theory and law* and *sociocultural* aspect of science shifted from naïve to mixed during the project. At first, Olivia defined theories as “*commonly held beliefs*” and laws as “*proof of concepts or a phenomenon.*” On the final interview, she referred to theory as “*an explanation of the natural phenomenon, which had been observed, tested, and confirmed,*” whereas laws as “*description of the natural phenomenon under certain circumstances.*”

Olivia’s survey responses demonstrated her naïve views on sociocultural aspect. She defined science as universal regardless of social and cultural values, but her views shifted to mixed views during the final interview and stated,

“Culture impacts so much... I think the environment plays a big role; we are in an urban environment that we do not have access to the same resources as in a school in a rural community. This plays a big role... The culture has the big effect.”

She thought culture had the significant effect in learning and doing science as different continents with different climates, and languages, cultures, foods, socioeconomic status might pose different perspective of the natural phenomena about the things that might see or not see.

Beliefs about teaching and learning. Olivia indicated her beliefs about students’ understanding of the science concepts, she stated,

“Meaningful learning is occurring when they are able to take the concepts that they are learning and apply them to examples that they see around them or that they can create themselves, I think, the application shows that they understand in a way that is beyond the example.”

The teacher understood that learning occurred when students applied them to new situations as well as through students’ questions, actions, interpretations, and use of appropriate vocabulary. She also assessed students’ learning through formative assessments including multiple choice tests and quizzes. For her role as a teacher, Olivia indicated,

“As a teacher, I see myself as a facilitator and motivator... I love the facilitating part, I love letting them be the guides to their learning, and maybe the resource, but not the only resource in the room, but the motivating part is always my goal to improve.”

Olivia made the connection between her role as a teacher and maximizing student learning through motivating and enhancing their interest in science learning. Olivia also thought to integrate research-based strategies, for instance, she said, *“I take everyday labs that we have research and access to try to make them ADI labs.”* She suggested converting inquiry-based activities into ADI model to promote collaboration among students that they could provide feedback on each other’s work and learn from each other. Olivia also addressed direct instruction as a way to maximize student learning to cover what students needed to learn based on standards.

Summary. Olivia thought learning about argumentation was helpful to experience the science from a constructivist standpoint through collaborative, student-centered activities. Olivia had high-quality knowledge of structural elements of an argument and dialogic process throughout the study. She held the limited understanding of student conceptions at the beginning, which improved and became high-quality during the project; however, she demonstrated limited knowledge of instructional strategies for argumentation over the course of the study. Olivia’s domain-specific beliefs involved consistently mixed knowledge of NOS in all aspects except the *difference between theory and laws* and *sociocultural* aspects, which shifted from naïve to mixed and indicated the improvement on her NOS understandings. There was a consistency between Olivia’s PCK of argumentation and domain-specific epistemological beliefs at the end of the study. The teacher talked about how aspects of NOS were embedded into argumentation activities as scientists used their creativity and imagination in developing and testing questions, designing the experiment, and collecting and analyzing the data; and new evidence could change the existing

scientific explanations. Olivia thought argumentation activities supported students' engagement in the exchange of the ideas among scientist to debate multiple perspectives on the same issue in parallel to her multiplist beliefs about nature of knowledge, which aligned with her beliefs about indicators of learning and maximizing student learning. Her PCK of argumentation supported integrating research-based strategies to maximize student learning in parallel to her belief about her role as a facilitator, which also aligned with her beliefs about nature of knowing as learning required perseverance and effort. She suggested that students should learn how to explore and research rather than reaching the information quickly, but she thought accumulated sources such as textbooks, articles, and internet as the sources of information. Olivia also suggested lecturing to teach the content as a way to promote student learning aligning with her beliefs about indicators of learning as the products including students' questions, interpretations, application of concepts in different situations, and results of formative assessments.

Teaching by Argumentation Instructional Model: Modified Enactment

Data collection around Olivia's teaching practice included 17.5 hours of classroom observation to understand how the teacher's PCK of argumentation and epistemological beliefs were translated into her practices. Olivia incorporated the argumentation instruction through modifying the specific stages of the ADI and using the resources provided during the PD program. She had implemented seven original ADI activities in one-year, and she also converted the inquiry-based labs into ADI model during the instruction. The researcher observed two ADI activities: 1) *Inheritance of Blood Type* as an original ADI activity, 2) An inquiry-based activity flipped to an ADI model. Table 18 presented the teacher's enacted and observed ADI activities throughout the study.

Olivia modified the implementation of ADI model based on her PCK of argumentation and epistemological beliefs. Her classroom practice was inconsistent with what was suggested by the

ADI model that the teacher focused on covering the standards through direct instruction before the investigation. In parallel to her beliefs about maximizing student learning, she lectured through pre-made visuals including powerpoint presentations and videos and promoted *Triadic Dialogue* rather than enhancing student's voice. In parallel to her beliefs about indicators of learning, the teacher utilized quizzes to assess students' understanding of concepts.

Olivia's implementation addressed the structural elements and dialogic aspect of argumentation. She provided the resources related to ADI activity including background information and investigation proposal and supported students to collaborate with each other in the design of the investigation, data collection and analysis, and development of the argument. For example, during the design of investigation, the teacher stated,

"You have to come up with what you gonna do for each of the different sets and how you know each of difference. Maybe, you can consider making a table... You need to refer to the resources you are given."

She did not explicitly define the structural elements of an argument, but guided students to present the data in the form of a table without addressing the difference between data and evidence. During the *Argumentation Session* stage, the teacher provided written comments about the structural elements of students' arguments on the whiteboards. For example, to improve students' arguments, she asked,

"Could you clarify your claim by wording it as a statement, possibly, a statement that answers your driving question? Could you strengthen your justification by explaining your evidence and why your evidence supports the conclusion you are drawing? What distinguishes your justification from your evidence?"

She also provided positive feedback and stated,

“Your evidence table is very descriptive; your justification is well-written and clear; your poster is well-organized.”

The teacher evaluated students’ posters to encourage them to improve their arguments without explicitly defining the claim, evidence, and reasoning conceptions.

Additionally, the teacher promoted the dialogic process during the instruction as she supported students to engage in sharing, listening to, critiquing, and building on each other’s explanations in groups. On the *Argumentation Session* stage, the teacher also promoted the *Gallery Walk* and reminded students to rotate and provide feedback on each other’s whiteboards. However, in parallel to the teacher’s knowledge of student conceptions about the dialogic process, students had difficulty in communicating and critiquing each other’s ideas to revise their arguments; student interaction was in surface-level. And, Olivia did not integrate the *Explicit and Reflective Discussion* stage to talk about the science content and aspects of NOS related to the investigation.

Furthermore, Olivia changed the implementation of *Writing an Investigation Report* stage as she did not emphasize the structural elements of an argument and utilize three questions suggested by the ADI resources oppose to her knowledge of ADI model. Instead, she provided a template as a scaffold for students’ writing including different sections such as experimental and control groups, hypothesis, background information, methodology, and conclusion parts. Olivia also integrated an online tool, *Google Doc* to provide real-time feedback on students’ writing and support collaboration among peers during the peer review process. Even though Olivia explained the peer review rubric and encouraged students to focus on the content, she did not ensure the quality and fairness of the review process, which was not double-blind.

Factors Influencing the Argumentation Instruction

Olivia held beliefs about student ability and indicated students' difficulty in efficiently engaging in the scientific processes and exploration through collaborative ADI activities rather than learning through lecturing and focusing on the right answers. Olivia linked the process skills to prior knowledge and stated,

“My students improved their ability to engage in scientific argumentation verbally. However, more support is needed to support them in their written argumentation skills. This may be primarily due to their below-grade-level reading and writing skills and unfamiliarity with argumentative writing.”

The teacher thought students improved their ability in oral communication, but they had weak reading and writing skills as well as math background. Olivia also referred to students' behavior and attendance issues due to their low motivation and socioeconomic status to participate in collaborative learning activities such as ADI investigations.

The teacher addressed the impact of district and standards for implementing the ADI activities. She stated, *“The standards that we have, they use to require habits of the mind, thinking about the characteristics of science...”* and added, *“In this district, you have to use all the research-based strategies to support your instruction.”* Olivia indicated that district prepared the standards to integrate the research-based strategies and nature of science concepts in parallel to the characteristics of ADI model. However, referring to test-preparation, she stated,

“They put stipulations on the schools on your priority status or school improvement grants; you cannot get out of this priority... The focus is heavily on the test. Teachers know that what they will produce the results on the test.”

She thought the school administrators gave priority to the school improvement grants and preparing students for the test through direct instruction even though they supported the implementation of ADI through hosting district mandated workshops, and she added,

“When we did the ADI labs in the previous semester, and then they took the test, they did not do well, but this semester there was not the lab, and we focused on direct instruction, they did amazingly at the top of the district on the Benchmark.”

Olivia thought “*Time is the problem*” to complete the full process of ADI and cover the units in large classrooms; and lack of resources and integrating technology challenged to monitor the ADI investigations, which might result in the development of alternative conceptions in students.

Cross-Case Analysis

To examine the similarities and differences in the individual cases, each case was compared to other cases to determine whether the participants shared certain features. The answers to three research questions are presented below related to the quality of teachers' PCK of argumentation, epistemological beliefs, instructional practices, and the other factors influencing the argumentation instruction.

Research Question 1: How does science teachers' participation in one-year PD program influence their PCK of argumentation and epistemological beliefs?

Across the four participating teachers, different patterns emerged concerning each teacher's PCK of argumentation and epistemological beliefs as well as knowledge of ADI model. In general, the teachers thought students' engagement in argumentation as both an innate and a social activity helped them develop scientific knowledge, form evidence-based explanations, and communicate their ideas through using the structural elements of arguments as well as through collaboration with their peers. Olivia, Eva, and Bella emphasized how engagement in the argumentation activities might develop students' interpersonal skills. Bella, Asia, and Olivia also considered argumentation as beneficial to teach science as a cyclic process and integrate NOS concepts into science instruction.

Concerning the instructional model, through the PD program, the teachers developed knowledge of stages of ADI model in different ways. For example, they addressed how to teach the design of the investigation, data collection, and analysis to develop arguments through focusing on engaging students in accurate and precise data collection and presenting the data in the form of charts, tables, and graphs. They also referred to *Gallery Walk* or *round robin* to encourage students to see each other's work, share ideas, and critique and build off of each other's opinions. However, the teachers had challenges in teaching through argumentation. They struggled with teaching how to

collect data and to define the structural elements of an argument, to promote the dialogic process, to explain the crosscutting concepts, and to ask questions to facilitate student thinking.

The second pattern that emerged from the study was related to the participating teachers' PCK of argumentation, which was assessed through the PCK of argumentation assessment (McNeill et al., 2016), informal conversations, and final interview. The teachers indicated improvements on their PCK of argumentation by the end of the study even though each teacher had a different change profile. The participating teachers held knowledge of argument structure and dialogic process before the PD program; however, their understanding of these aspects of argumentation was different and changed in distinct ways during the project. For example, the results of PCK of argumentation assessment indicated a consistency for their pre-assessment scores in total for three teachers (Asia, Bella, and Olivia); they responded 12 items correctly. Asia had the highest scores, and Eva had the lowest scores across three PCK of argumentation assessment among four teachers. Bella experienced a decrease in her assessment scores, which did not indicate any change in her views. Olivia proposed high-quality knowledge of both argument structure and dialogic process throughout the study. The summary of the participants' PCK of argumentation profile presented in Table 19.

The nature of the data sources for PCK of argumentation assessment (quantitative measure) and informal conversations and final interview (qualitative measure) indicated some inconsistencies and change in the science teachers' PCK of argumentation. For example, Asia's limited views about the evidence conception on the pre-assessment shifted towards high-quality views after the PD program consistent with her explanations on the final interview even though she provided limited views on the post2-assessment.

Table 19

Each teacher's PCK of argumentation profile over the course of the study

	Asia	Bella	Eva	Olivia
Argument structure	(E) ^a : limited ^b to high to limited (high-quality ^c) (R) ^a : high-quality	(E): limited to high-quality (R): high-quality to limited	(E): high-quality to limited to high-quality ^b (R): limited to high-quality ^c	(E): high-quality (R): high-quality
Dialogic process	(SI) ^a : high-quality (CC) ^a : high-quality	(SI): limited (CC): high-quality to limited to high-quality ^c	(SI): limited to high-quality ^c (CC): limited to high-quality ^c	(SI): high-quality (CC): high-quality
Student conceptions	Limited to high-quality^b Students have difficulty in - Providing relevant evidence - Providing high-quality evidence - Providing proper justification - Articulating thoughts - Providing and receiving feedback			
Instructional strategies	Limited Scaffolding strategies: Modelling, graphic organizer, use of rubric, exemplars Think-pair-share & Use of visuals			
	- Reading passages - Asking probing questions - Giving situations about an event or phenomenon	- Annotation strategies - Combating issues - Hands-on activities	- Annotation strategies - Direct instruction - Writing reflections - Conversation cards - Preparing think-sheet	- Providing high-quality evidence - Using personal opinion as evidence - Providing sufficient reasoning - Communicating ideas - Evaluating accuracy of others' claims - Use of CER framework - Annotation strategies - Discrepant events - Conversation cards - Open-ended questions

a: Evidence (E), reasoning (R), student interaction (SI), competing claims (CC)

b: Teachers' unclear or incomplete responses without detailed rationale is evaluated as limited or low-quality, accurate definitions of conceptions and their connections with accurate rationale and example is evaluated as high-quality on the conceptions of PCK of argumentation assessment

c: Even though teachers' responses on the PCK of argumentation assessment indicated their limited views, their responses during the informal conversations and final interview provided their high-quality knowledge on this dimension.

Bella's high-quality knowledge of competing claims on the pre-assessment was limited on the post1- and post2- PCK of argumentation assessments although her explanations on the final interview were in high-quality on the competing claims conception. Eva had limited knowledge of the dialogic aspect of argumentation across three PCK of argumentation assessment, but her views were in high-quality on this aspect during the final interview.

There was also consistency on the participants' responses between the PCK of argumentation assessment scores (quantitative measure) and informal conversations and the final interview (qualitative measure). For example, Bella's limited knowledge of evidence conception on the pre-PCK of argumentation assessment increased to high-quality on the post1- and post2-assessments as well as the final interview; whereas Bella's high-quality knowledge of reasoning conception on the pre-assessment decreased to limited on the post1- and post2-assessments as well as final interview. Moreover, the teachers indicated consistently limited or high-quality views on the structural and dialogic aspects of argumentation. Olivia held high-quality knowledge of argument structure and dialogic aspects, Asia possessed high-quality knowledge of reasoning and dialogic process, and Bella had limited knowledge of student interaction throughout the study.

Professional development experience and explicit argument instruction helped teachers develop knowledge of student conceptions for both structural and dialogic aspects of argumentation. The teachers experienced a positive shift towards high-quality knowledge of student conceptions as they provided the rationale for students' challenges in constructing scientific and sound arguments by the end of the study. There were three commonalities across four teachers' knowledge of student conceptions regarding argument structure and dialogic aspect. First, the teachers thought students had difficulty in providing relevant or high-quality evidence. They indicated that students might provide evidence not related to the claim or provide claim not related to evidence. Bella and Olivia also

indicated that students provided personal experience or opinion as evidence. Second, the teachers referred to students' challenges in academic language to develop scientific knowledge and produce sound justifications. Lastly, the teachers talked about students' frustration with the ADI process as students usually focused on the correct answers; so that, they had difficulty in communicating their ideas in oral or written format. These teachers thought students did not listen to their peers to understand that they might have valuable information or students had difficulty in providing or receiving feedback or evaluating each other's ideas.

To address students' challenges in providing the structural elements of an argument, the teachers suggested limited instructional strategies that could not promote argumentation instruction in-depth. These teachers did not illustrate how an instructional strategy would look like in a classroom context and how to promote argumentation in-depth. The teachers considered integrating scaffolding strategies, building academic language, and promoting the dialogic process of argumentation. Regarding scaffolding strategies, the teachers preferred modeling the data collection and analysis and using graphic organizers, exemplars, sentence starters or rubric to guide the construction of arguments. In terms of building the academic language, the teachers thought using annotation strategies such as highlighting, underlining, and circling the conceptual vocabulary or citing evidence from the text, using visual resources such as videos or powerpoint presentations, providing different levels of reading passages or academic words and addressing real-life applications of concepts. For the dialogic aspect of argumentation, the teachers referred to group work activities to promote students' productive discussions through think-pair-share or hands-on activities, real-world phenomena, and discrepant or competing events. The teachers also thought eliciting students' ideas through providing conversation starter cards or asking open-ended or probing questions.

The third pattern that emerged from the study was related to participants' beliefs about teaching and learning. These teachers' beliefs about their role as a teacher were categorized as either facilitator or dispenser of the information. Asia and Olivia considered their role as a *facilitator*, but Eva and Bella considered their role as both a *facilitator or guide* and the *dispenser of the information*. The teachers who embraced the role of a facilitator focused on guiding students' learning to discover on their own, collaborate and figure out by themselves, and develop higher-order thinking. The teachers who considered their role as the source of information emphasized promoting lecture-based instruction through using the powerpoint to teach the fundamental concepts and their real-life applications. Additionally, the teachers' beliefs about learning science addressed their beliefs about indicators of learning as well as how they preferred enhancing student participation. These teachers had similar beliefs about indicators of learning even though there were slight differences. The teachers thought students' explanations, questions, and their responses on formative assessments (e.g., exit tickets, clicker questions, multiple-choice tests, quizzes, and rubrics) were the indicators of learning. Asia focused on work products such as investigation reports; Eva thought collaboration with peers; and Olivia indicated their use of appropriate vocabulary as the indicators of students' learning. Eva and Olivia also thought students would learn the science concepts if they applied the concepts to new situations and made connections to real-life situations.

Furthermore, these teachers had mixed beliefs that they addressed both student-centered and teacher-centered instruction to maximize student learning. They supported lecturing to cover the content and make students master the standards through power point presentations, visual sources, and demonstrations. The teachers also supported the use of research-based strategies, differentiated instruction to address diverse student needs, and developing students' social and emotional learning skills to enhance their participation. For example, Bella addressed the

importance of the teacher-caring on students' learning and thought a teacher could build a good relationship with students. Olivia focused on acting as a motivator of students' learning to increase their interest, and Eva addressed the role of improving students' metacognitive thinking to enhance students' learning.

The fourth pattern that emerged from the study was related to participants' epistemological beliefs regarding domain-general and domain-specific epistemological beliefs, which were assessed through Epistemological Beliefs Survey, VNOS-270 questionnaire, informal conversations, and interviews. Table 20 presented the summary of the results from EBS, and Table 21 demonstrated the relationship between the teachers' domain-general beliefs and domain-specific beliefs.

Epistemological Beliefs Survey (EBS) (Wood & Kardash, 2002) was implemented at the end of the study to assess the participants' personal epistemology and supported by the teachers' explanations during the informal conversations. The results of the survey and informal conversations indicated that the teachers mostly held multiplist or mixed domain-general epistemological beliefs that addressed the knowledge as subjective, uncertain, and depending on personal experience; but, on a few dimensions, they indicated evaluativist beliefs that they defined knowledge as complex based on evidence-based explanations. For example, Asia was the only teacher, who held evaluativist views about nature of knowledge that she described knowledge as evaluated based on evidence; and Olivia was the only teacher, who had evaluativist beliefs about controlling and influencing factors as learning required sustainable effort.

Table 20

The results of EBS survey for each dimension

	Structure of Knowledge (11 items)	Attainability of Objective Truth (3 items)	Speed of Knowledge Acquisition (8 items)	Characteristics of Successful Students (5 items)	Knowledge Construction and Modification (11 items)	Total
Asia	37	10	33	20	41	141
Bella	31	10	36	13	46	136
Eva	36	9	32	22	41	140
Olivia	40	10	32	18	42	142

Table 21

The comparison of dimensions of epistemological beliefs

Teacher	Knowledge	Knowing	Teaching	Maximize Learning	Indicators of Learning
Asia	Evaluativist	Mixed	Facilitator	Research-based Differentiation Lecturing Emotional support	Explanations, Questions, Assessment Investigation reports
Bella	Multiphist	Mixed	Facilitator Source	Differentiation Lecturing Teacher-caring	Explanations, Questions, Assessment
Eva	Multiphist	Mixed	Facilitator Source	Research-based Lecturing Metacognitive thinking Classroom rules	Explanations, Questions, Assessment, Collaboration Connection to real-life
Olivia	Multiphist	Mixed	Facilitator Motivator	Research-based Lecturing	Explanations, Questions, Assessment, Vocabulary Connection to real-life

The participating teachers' knowledge of NOS profile as domain-specific epistemological beliefs indicated that these teachers held mixed views on most of the aspects of NOS by the end of the study. Their responses for different aspects of NOS were classified into categories related to consistently naïve and mixed views, and views that changes occurred. The three of four teachers held mixed views on the *subjectivity* aspect of science at the beginning and the end of the PD program, and by the end of the study. The one in four teachers indicated naïve views, and one teacher held mixed views about the *sociocultural* aspect of science throughout the study. Additionally, the three of four teachers possessed mixed views on the *creativity and imagination* aspect throughout the study. The two of four teachers indicated consistently mixed views on the *tentativeness, empirical-embeddedness, and the difference between theory and laws* aspects during the project. These results indicated that the teachers had difficulty in changing the *subjectivity, creativity and imagination, and sociocultural* aspects of science.

The positive changes were also evident that the teachers improved their knowledge of certain aspects of NOS from naïve to mixed or from mixed to informed views over the course of the study. Several teachers shifted their naïve views towards mixed understandings on *creativity, empirical-embeddedness, the difference between theory and laws, and the difference between observation and inference*. However, one teacher shifted her view of *sociocultural* aspect from mixed to informed views, and another teacher changed her naïve views of *sociocultural* aspect to mixed views by the end of the study.

However, the negative changes were evident on one teacher's views that her mixed views on the *empirical-embeddedness* moved to naïve, and another teacher's informed views on the *subjectivity* aspect were mixed views by the end of the study. On certain aspects, even the changes occurred on the teachers' initial views, two teachers recovered to their initial views by the end of the

study. For example, one teacher's informed views on the *sociocultural* aspect became mixed and mixed views on the *tentativeness* aspect became naïve by the end of the PD program, which shifted to their initial views on these aspects at the end of the school year. Another teacher's informed views on the *subjectivity* aspect became mixed, and informed views on *the difference between observation and inference* became mixed by the end of the PD program, which shifted to informed views by the end of the study. Negative shifts were evident on the *subjectivity* and *empirical-embeddedness* aspects, and these teachers recovered to their initial understandings on the *tentativeness* and the *difference between observation and inference* aspects.

Summary. Asia's evaluativist views about nature of knowledge were parallel to her beliefs about nature of knowing, role as facilitator, maximizing student learning through differentiation as well as her mixed views on most of the aspects of nature of science. Asia also thought integrating research-based strategies such as argumentation to promote collaboration and discussion among peers and critique each other's ideas in parallel to her beliefs about nature of knowledge addressing knowledge as complex and tentative and about nature of knowing referring to learning as a gradual and effortful process. Aligning with her knowledge of NOS and PCK of argumentation, she thought supporting students to make evidence-based explanations, explore new evidence through research rather than memorizing facts, listen to the alternative ideas on the same phenomena, and compare and contrast the differences and similarities across groups to make inferences based on observation and evidence. However, Asia also indicated that learning required an innate ability consistent with her beliefs about the source of knowledge as accumulated findings and maximizing student learning through lecturing, but inconsistent with her evaluativist beliefs about nature of knowledge and beliefs about the source of knowledge as experience.

Bella, Eva, and Olivia held multiplist views on their beliefs about nature of knowledge as co-constructed and changing based on the individual experiences; they recognized the subjective

dimension of learning that each individual might have equally-right opinions. Eva and Bella's multiplist beliefs about nature of knowledge aligned with their beliefs about nature of knowing addressing controlling factors as both an innate ability and effortful process, process of knowing as gradual and using accumulated findings. They held beliefs about the role of a teacher as both source of information and facilitator and their beliefs about maximizing student learning through both teacher-centered and student-centered approaches. Eva also thought that people learned through experience to refer the experiential aspect of the source of knowledge. However, Olivia held beliefs about the process of knowing as perseverance and her tendency to act as a facilitator were consistent with her consistently mixed views on the tentativeness, creativity and imagination, subjectivity, empirical-embeddedness as well as the difference between observation and inference. Bella, Eva, and Olivia did not directly value critical thinking skills. They thought students learned science concepts through lecturing as well as they utilized differentiation or research-based instruction. Olivia's high-quality PCK of argumentation on all dimensions was inconsistent with her multiplist epistemological beliefs, but consistent with her beliefs about nature of knowing as requiring consistent effort and occurring in a gradual process and beliefs about teaching science as the facilitator. Eva and Bella's epistemological views were consistent with their PCK of argumentation. Bella had limited knowledge of reasoning conception, which aligned with her lack emphasis on the critical thinking skills, whereas Eva valued the students' engagement in argumentation activities to enhance their critical thinking skills.

Participants' beliefs about nature of knowledge were parallel to their consistently mixed knowledge of specific aspects of NOS by the end of the study. For example, Bella, Eva, and Olivia's beliefs about nature of knowledge as subjective and uncertain were parallel to their consistently mixed views about the subjectivity aspects of science. Asia's evaluativist views about nature of knowledge as requiring evidence-based explanations were aligned with her

consistently mixed views about tentativeness, empirical-embeddedness, and creativity and imagination aspects of nature of science.

Research Question 2: How are teachers' PCK of argumentation and epistemological beliefs reflected on their practice?

The participating teachers' implementation was either aligned or modified with the expectations of ADI instructional model in parallel to their PCK of argumentation and epistemological beliefs. Asia's practices were aligned with what the model was intended; however, Bella, Eva, and Olivia modified the specific stages of the model while using the resources provided during the PD program. These teachers' integration of the instructional model was parallel to their PCK of argumentation and epistemological beliefs even though there were a few improvising conditions.

The first pattern of teachers' implementation focused on the structural elements of an argument, which was parallel to the teachers' PCK of argumentation and the expectations of the ADI model. For example, Asia and Eva focused on defining the evidence and justification conceptions and guiding students in constructing high-quality arguments in parallel to their high-quality knowledge of argument structure and their knowledge of student conceptions. Bella highlighted the students' difficulty in the use of justification conception. In terms of instructional strategies, during the instruction, Bella and Asia prompted students to cite evidence from the text; Asia used the ADI poster as a model, and Eva provided the sentence starters to scaffold the construction of arguments in parallel to their knowledge of instructional strategies.

The second pattern of the teachers' implementation focused on the dialogic aspect of argumentation, which encouraged students to collaborate, exchange their opinions, and build on each other's ideas during the group-work activities or whole-class discussions. However, there were differences among the teachers on how they promoted dialogic interaction. Asia and Olivia

promoted student interaction mostly through *Gallery Walk*; Bella and Eva through *group presentation* format to encourage students to collaborate to share, evaluate, and revise the structural components of arguments through listening to what each group has done, critiquing and building off of each other's ideas. In Bella's class, each group presented alternative claims to answer the research question; the differences in each group's arguments promoted competing claims, but student interaction among the groups was low. On the other hand, Eva encouraged students to work in groups through preparing a "Think-sheet" as a guide to develop background information and decide how to design the experiment and collect data. Eva also prompted students to provide feedback on their own posters in their groups and talk about what students have done, why they have done, and what they needed to do next time to improve their work.

The third pattern of the teachers' implementation focused on their epistemological beliefs, which were apparent in their classroom practices in different ways. Asia and Eva made explicit references to characteristics of NOS during the instruction even though Bella and Olivia did not have any discussion on the aspects of science. For example, Asia promoted discussions in the form of a *Triadic Dialogue* about the work of scientists to remind students about the design of investigation and data collection and analysis through collaborating with others to see different views on a phenomenon. However, she did not provide feedback on students' design and methodology to improve their creativity and imagination; instead, she focused on promoting students' enthusiasm to enhance their participation towards science activities.

Participants' domain-general beliefs and their beliefs about science teaching and learning also reflected on their implementation of the argumentation. These teachers acted as both the facilitator and the source of the information during the instruction in parallel to their beliefs about maximizing student learning and their multiplist domain-general epistemological beliefs. Asia's evaluativist domain-general beliefs were related to her role as a facilitator and her approach to knowledge as

complex and integrated through promoting the dialogic process. However, there were a few inconsistencies. For example, Asia's evaluativist views about nature of knowledge contradicted with her beliefs about nature of knowing that she believed learning as both an innate ability and required consistent effort. Her evaluativist views about nature of knowledge were also opposed to her beliefs about maximizing science learning that the teacher considered utilizing both student-centered and teacher-centered approaches to enhance student participation. Moreover, Olivia held multiplist views about nature of knowledge, but she indicated evaluativist views about controlling and influencing factors that she believed learning as sustainable effort and considered her role as a facilitator rather than the source of the information. In practice, she lectured to teach the science content in parallel to her beliefs about maximizing student learning.

Summary. The four teachers' implementation of argumentation was categorized based on their use of structural elements, dialogic aspects of argumentation as well as their epistemological beliefs. The teachers' definition of argument structure during the instruction was parallel to their PCK of argumentation. They guided students to construct high-quality arguments and utilized instructional strategies in parallel to their knowledge of instructional strategies for argumentation. Moreover, each teacher promoted the dialogic process through either Gallery Walk or group presentation; but the quality of student interaction and competing claims were different in each teacher's classroom. The teachers' epistemological beliefs were also evident in their classroom instruction as they acted as both a facilitator and source of knowledge in parallel to their mixed views about nature of knowing and beliefs about maximizing student learning. Even though the teachers mostly held mixed views about characteristics of science, only Asia and Eva addressed these aspects during the instruction explicitly. The teachers' knowledge of NOS was not significantly integrated into their classroom instruction throughout the study.

Research Question 3: What other factors do teachers report as influencing the argumentation instruction?

The participating teachers addressed the other factors influencing the argumentation instruction referring to student-related and external factors. These teachers indicated their beliefs about student ability in terms of process skills, prior knowledge, student characteristics, and attitudes. Summary of the factors that the teachers reported as influencing the argumentation instruction presented in Table 22. They thought students could engage in the process of argumentation, but students focused on the right answers rather than arguing in a scientific way in designing the investigation, collecting meaningful data, and explaining their reasoning. Only Asia focused on students' social skills during the science experiments and addressed students' challenges in understanding how scientists work and communicate their answers such as providing and receiving feedback to revise their work. In terms of prior knowledge, these teachers particularly focused on students' low literacy skills such as poor reading and writing skills as a barrier to their engagement in the argumentation. The participants also addressed different student characteristics as factors influencing the implementation of argumentation through emphasizing the diverse student profile in their classrooms including general education, ESOL, or gifted students. The teachers also indicated that students' socioeconomic status had an impact on their engagement with the new strategies such as the ADI process as well as understanding the science concepts. For example, Bella indicated that majority of students deal with poverty in urban schools so that they and their families do not value and promote education. Another factor that the participants influenced the argumentation instruction was related to students' attitudes such as students' study habits, motivation, attendance, and behavior problems.

Table 22

Other factors mediating the argumentation instruction

	Asia	Bella	Eva	Olivia
Student Ability				
Process	• Measurements, sampling strategies • Low social skills	• Improved ability to engage in ADI activities	• Improved ability in data collection	• Improved ability to engage in scientific processes and oral conversations
Prior Knowledge	• Low reading skills	• Low math, reading and writing skills	• Poor reading and writing abilities	• Low writing, math, and reading skills
Student Characteristics		• Socioeconomic status	• Diverse students (ESOL or gifted)	• Economic status
Attitudes	• Emotional • Behavior problems	• Motivation	• Poor study habits • Behavior, motivation • Irresponsibility for their learning	• Behavior and attendance issues • Motivation
District/ Standards	• Standards and crosscutting concepts are related to ADI	• Standards addressing science and engineering practices, NOS, and crosscutting concepts • District to push teachers to teach for the test	• ADI supported by district; aligned with the standards	• ADI as parallel to research-based strategies and NOS concepts suggested by standards
School context	• Transient population of students in crisis • Various background knowledge in science	• Collaborating with other teachers in her school	• Lack content teachers at the school • Lack collaboration activities • Class size • Interruption during the lesson	• School administrators put priority on seeing the results
Curriculum/ Testing	• ADI to prepare students for test • Time to complete an ADI activity	• No flexibility over the curriculum • Lack of resources and time	• ADI to prepare students for the test • Time • Resources	• Test is priority for the district • Time and lack of resources • Integrating technology

The participating teachers proposed the mediating factors as the district and standards, curriculum and testing, and school context as external factors. These teachers thought district supported the implementation of ADI model that was aligned with the standards and naturally provided an inclusive process to integrate the best practices into science instruction including investigation, research, writing, and peer review. Bella and Olivia particularly indicated that district and standards supported integrating the research-based strategies, nature of science concepts, and the habits of mind into science teaching through ADI activities. In contrast, Asia, Olivia, and Bella emphasized that the teachers did not have flexibility over the curriculum as the textbooks were addressing the scientific argumentation and nature of science on a smaller scale. Besides, district's focus on End-of-Class (EOC) tests led to school administrators and school context to give priority to test preparation through direct instruction, which promoted less collaboration across departments in each school. There were also other factors related to school contexts such as time, resources, and class size. These teachers mostly underestimated the time necessary to complete an investigation. Although the PD program provided resources such as whiteboards and markers or materials to conduct ADI investigations, the teachers did not have these materials in their own school context that made the implementation of the ADI model difficult. Class size was also a factor influencing argumentation instruction due to students' behavior issues.

CHAPTER V

DISCUSSION

This study explored whether science teachers might enhance their PCK of argumentation and epistemological beliefs through attending one-year professional development program and whether they might translate their PCK of argumentation and epistemological beliefs into science instruction. The study aimed to address a gap in the literature to explore the relationship between in-service science teachers' both domain-general and domain-specific epistemological beliefs, PCK of argumentation, and teaching practice in a single study while engaging in an intensive professional development experience.

These results provided the evidence that four teachers attended an intensive professional development program, and they experienced slight positive or negative shifts on their PCK of argumentation and epistemological beliefs. For example, Asia's limited views on the evidence conception were in high-quality during the informal conversations and final interview; and Bella's naïve views on the empirical embeddedness, the difference between observation and inference, and the difference between theory and laws shifted towards mixed views. However, participating teachers also held consistent views in certain conceptions of PCK of argumentation and certain aspects of NOS. For example, Bella held limited views on the student interaction conception at the beginning and end of the PD program and by the end of the study. Asia's knowledge of tentativeness, creativity and imagination, empirical-embeddedness, the difference between theory and law, and sociocultural aspects of science were mixed throughout the study. Olivia held consistently mixed knowledge of tentativeness, creativity and imagination, subjectivity, the difference between observation and inference, and empirical aspects of science.

These results suggested that the improvements in PCK of argumentation and epistemological beliefs might not be the case for these teachers. Additionally, the teachers' implementation was either aligned or modified with the expectations of argumentation instructional model in parallel to their PCK of argumentation and epistemological beliefs. Moreover, participating teachers referred to the factors mediating the implementation of argumentation instruction model as their beliefs about student ability, district and standards, curriculum and testing, and school context. The study resulted in the following findings.

Changes in PCK of Argumentation and Epistemological Beliefs

First, the participating teachers' PCK of argumentation had different change profiles in terms of both structural and dialogic aspects of argumentation. These teachers started to the professional development program with different levels of knowledge of argument structure and dialogic process. The analysis of the teachers' PCK of argumentation assessment scores, informal conversations, and final interview indicated that Olivia consistently provided high-quality definitions of structural elements and dialogic aspect of argumentation; Bella, Asia, and Eva experienced positive shifts from their low-quality to high-quality views. Consistent with previous research (McNeill & Knight, 2013; Marco-Bujosa et al., 2017; Sadler, 2006; Sampson & Blanchard, 2012; Simon et al., 2006), these results suggested that one-year professional development on argumentation instruction improved these science teachers' PCK of argumentation. However, Bella's change profile was different from other teachers; she held consistently limited views about student interaction; she improved her knowledge of evidence conception from limited to high-quality views. She experienced a negative change in her knowledge of reasoning and competing claims conceptions even though her knowledge of competing claims were high-quality during the informal conversations and final interview. Bella

improved her knowledge of argument structure and dialogic process after the intervention, but her little emphasis on these aspects throughout the year (not implementing any ADI activity after the intervention) might result in negative shifts on these dimensions of PCK of argumentation. This result was consistent with the findings from Marco-Bujosa et al. (2017) that science teachers might improve their understandings of dialogic aspect, but they might decrease their knowledge of argument structure depending on how these teachers interpreted the curriculum materials and how they promoted argumentation instruction.

These teachers held limited knowledge of student conceptions for both structural and dialogic aspects of argumentation at the beginning, and they experienced a positive shift towards high-quality views as they provided the rationale of students' challenges in parallel to results of previous studies. The participating teachers' enhanced knowledge of student conceptions aligned with the results of the published literature. These teachers indicated that students struggled with collecting and analyzing multiple evidence to support a claim and construct high-quality arguments (Choi et al., 2015; Evagorou & Osborne, 2013; Sampson et al., 2013). In terms of justification conception, the participating teachers' students struggled with explaining the link between evidence and claim through scientific principles (e.g., Berland & McNeill, 2010; Knight-Bardsley & McNeill, 2016; McNeill et al., 2006; Sampson et al., 2013). For the dialogic aspect of argumentation, the teachers thought students struggled with communicating their ideas, listening to alternative ideas, critiquing each other's claims, and making revisions (Berland & Reiser, 2011; McNeill et al., 2006; Sampson et al., 2013). Different from previous studies, the participants of this study documented that students' lack of academic language skills might result in challenges to build the knowledge of science content as well as to provide high-quality justification.

To address students' challenges in both argument structure and dialogic aspect of argumentation, these teachers suggested low-quality instructional strategies that were not able to promote argumentation in-depth; the teachers did not illustrate how an instructional strategy would look like in a classroom context (McNeill et al., 2017). The teachers considered integrating the scaffolding strategies to teach how to develop arguments (McNeill et al., 2006). They suggested providing graphic organizers, sentence starters, rubrics, and exemplars (Choi et al., 2015; McNeill et al., 2006; Simon et al., 2006); defining the elements of an argument (McNeill & Krajcik, 2008); and providing the models of good and bad data sets to model the high-quality arguments (Gonzales- Howard et al., 2015). These teachers particularly focused on teaching the academic language through addressing the real-life applications of concepts (McNeill & Krajcik, 2008) and integrating visual resources (Osborne et al., 2013). Different from the existing literature, the participating teachers suggested the use of annotation strategies to cite the evidence from the reading text and integrating different levels of reading passages and the list of words to support students' in developing sound arguments.

Furthermore, the strategies that the teachers suggested to promote accountable talk were also parallel to what the published literature reported. These teachers thought integrating think-pair-share activities (Choi et al., 2015; Osborne et al., 2013; Sadler, 2006), hands-on tasks (Roth & Garnier, 2008), and asking probing questions (McNeill & Pimentel, 2010; Pimentel & McNeill, 2013) to promote student interaction and competing claims through small group and whole class discussions. This study also explicated that the teachers suggested modeling the dialogic process such as how to interact and respond to critique and build off of each other's ideas. Eva and Olivia supported the use of conversation starter cards, which was provided by the PD program to scaffold the students' discussions.

Second, besides the change in participating teacher's PCK of argumentation, the teachers in this study held different epistemological beliefs' profiles. This study approached teachers' domain-general epistemological beliefs as stable and multidimensional (Sinatra, 2016; Schommer, 1990). The PD program in the current study focused on argumentation instruction through an instructional model and assumed that the in-service science teachers in this study had already experienced the academic training in their college years and held more established and stable domain-general epistemological beliefs. Four in-service science teachers held evaluativist or multiplist beliefs about nature of knowledge and beliefs about nature of knowing. It was apparent that even though these teachers developed sophisticated beliefs about nature of knowledge, they still held mixed beliefs about nature of knowing. Some teachers continued to believe that learning was an innate ability and considered utilizing accumulated findings as resources; but, they also thought that learning required hard work and experience as well as evolved in a gradual process. In parallel to the results of Buehl and Fives (2009) and Braten and Ferguson (2015), these teachers considered sources of knowledge as formalized bodies of knowledge including articles, textbooks, internet, websites, and social media, but Eva and Asia also believed that individuals' experiences or interactions were the practical-based sources of knowledge.

Third, four teachers' participation in this professional experience on argumentation did not result in substantial changes in their knowledge of NOS. The current study provided the evidence that the in-service middle or secondary science teachers could have consistent views, experience positive or negative shifts, or experience a shift, but return to their initial understandings after the interventions. The three of four teachers had consistently mixed views on the *creativity* and *subjectivity* aspects; the two of four teachers held consistently mixed views on the *empirical-embeddedness*, *tentativeness*, and *the difference between observation and inference* aspects. The

two teachers possessed naïve views on the *sociocultural* aspects across three VNOS-270 questionnaires. These results were different from Posnanski (2010)'s findings that these teachers mostly held mixed and unchanged understandings on certain aspects of NOS, whereas 18 of 22 teachers in Posnanski (2010)'s study improved their more naïve understandings towards more informed views of NOS aspects. In the current study, positive shifts were observed on the teachers' naïve understandings of *empirical-embeddedness*, *creativity*, *the difference between observation and inference*, and *the difference between theory and laws* aspects towards mixed views. These results aligned with the Donnelly and Argyle (2011)'s findings that their participants experienced improvements on *empirical-embeddedness*, *creativity*, *subjectivity*, *tentativeness*, and *the difference between theory and laws*. Additionally, in this study, negative shifts were evident on the *subjectivity* and *empirical-embeddedness* aspects; and, these teachers recovered to their initial understandings on the *tentativeness* and *the difference between observation and inference* aspects.

According to Mulvey and Bell (2017), middle science teachers had prior experiences in scientific contexts and had already exposed to the practices of scientists through their academic courses. Middle science teachers might experience positive changes in their knowledge of NOS through discussing in different contexts such as the history of science or socioscientific contexts, and they might retain their knowledge after a period. Similar to this study, positive shifts occurred that the teachers' naïve views shifted towards mixed views or mixed views shifted towards informed views on some aspects of NOS. For example, Olivia and Bella enhanced their naïve views on the *difference between theory and laws* and *sociocultural* aspects to mixed views by the end of the study. These results were consistent with the results from Akerson et al. (2009) and Posnanski (2010) studied with elementary in-service science teachers, and Donnelly and Argyle (2011) studied with elementary, middle, and high school science teachers. In particular, Posnanski (2010) provided

evidence that elementary in-service science teachers' participation in an activity-based environment including journal readings, scientific research techniques, and inquiry-based instruction resulted in improvements in their knowledge of NOS. These studies reported that NOS instruction across all grade levels could improve the teachers' NOS conceptions after the PD program focusing on explicit NOS and argumentation instruction.

Moreover, recent studies conducted by Bell and colleagues (2011, 2016) and Mulvey and Bell (2017) had a conceptual change approach to NOS instruction and provided the empirical evidence that both pre-service and in-service science teachers' enhanced NOS understandings retained ten months after one-week summer professional development. Bell and colleagues used the Vosniadou (2003)'s conceptual change perspective as a theoretical framework. Conceptual change approach aimed to create a conceptual conflict in learners' existing conceptions to stimulate the need for replacing their ideas with more sophisticated scientific thinking as intelligible, to solve the problems and be consistent with the other types of knowledge as plausible, and to be extended to new areas of inquiry as fruitful through discussion and reflection (Abd-El-Khalick & Akerson, 2004; Posner, Strike, Hewson, & Gertzog, 1982; Vosniadou, 2003). Their studies indicated that teachers could maintain the shift in their knowledge of NOS after the intervention through the explicit-reflective approach to NOS instruction including activities with mixed contextualization- within a context continuum either connected or not connected to specific science content such as the history of science, socio-scientific issues, and science inquiry contexts. However, the PD program in this study did not use a conceptual change perspective. The participants' prior knowledge of NOS aspects was assessed through VNOS-270 questionnaire. The PD designers and the researcher did not know the teachers' responses by the end of the study and did not target their prior conceptions to promote modification. Different from the results of Bell et

al. (2011, 2016) and Mulvey and Bell (2017), in the current study, some teachers did not retain their enhanced understandings of NOS conceptions a period after the PD program that negative shifts were evident. This result was consistent with the findings of Akerson et al. (2006), which also did not have a conceptual change perspective. For example, Eva changed her improved mixed knowledge of *empirical-embeddedness* to naïve views; and Asia shifted her informed knowledge of *subjectivity* to mixed views ten months after the intervention.

Akerson and colleagues (2006) argued that teachers with sophisticated epistemological position could engage in metacognitive thinking and deep reflection and retain their enhanced NOS understandings. However, teachers with low-level epistemological positions might focus on the right answers and not believe that ideas might change with new evidence. The fact that even though four in-service science teachers in this study believed either knowledge was complex and integrated or knowledge was uncertain and subjective that all ideas were equally valid, they did not experience significant changes in their knowledge of NOS. Their knowledge of specific aspects of NOS was either unchanged or slightly improved after the PD program and through one-year explicit argumentation instruction. These results indicated that the teachers with evaluativist and multiplist beliefs should be open to commit to the new ideas that can support or facilitate the change in their knowledge of NOS.

Fourth, the analysis also provided the participating teachers' beliefs about teaching and learning science as domain-specific epistemological beliefs. Eva and Bella considered their role as both a facilitator and source of information; Asia and Olivia embraced the role of the facilitator. These teachers focused on the work products and enhanced students' learning through research-based approach, differentiation techniques, or teacher-centered strategies. The results were consistent with the previous research that the teachers supported the implementation of

argumentation as a process rather than a product to enhance students actively involved in their own knowledge construction and to develop science content (Brown & Melear, 2007; Crawford, 2007; Rushton et al., 2011). In parallel to the findings of previous studies (e.g. Fives & Buehl, 2012; Herrington et al., 2011; Smith & Southerland, 2007), some teachers supported the teacher-centered strategies to maximize student learning based on personal factors such as teacher knowledge, collaboration opportunities, social, and cultural issues or external factors such as resources, curriculum, policy, or administration.

Furthermore, consistent with results from Sinatra and Kardash (2004), the four teachers held beliefs about nature of knowledge and knowing consistent with their beliefs about teaching and learning science. For example, in this study, Eva believed that knowledge was uncertain and depended on individuals' subjectivity, and learning required both innate ability and perseverance in a gradual process. These teachers tended to believe that a teacher could act both as a facilitator and as a source of information and maximize student learning through both student-centered and teacher-centered instruction. Olivia also held multiplist beliefs about nature of knowledge consistent with her beliefs about her role as the guide for students' learning that students could experience the ownership of their own learning process while constructing knowledge. She also had beliefs about nature of knowing as requiring consistent effort and developing gradually, but thought to utilize accumulated findings as textbook, encyclopedias or internet as the sources of knowledge. Aligning with the suggestions from Liu & Roehrig (2017), the results of this study illustrated the consistency between these science teachers' domain-general and domain-specific epistemological beliefs, but this consistency might not be apparent for each case in a different context such as in a different grade level or with teachers of higher-achieving or lower-achieving students or students with diverse backgrounds.

Translation of PCK of Argumentation and Epistemological Beliefs into Practice

The teachers' implementation was either aligned or modified with the expectations of argumentation instructional model in parallel to their PCK of argumentation and epistemological beliefs. The results suggested that the teachers' epistemological beliefs mediated the translation of the teachers' PCK of argumentation into instruction. The teachers' implementation of argumentation was aligned with their PCK of argumentation. However, there were lessons that the teachers also utilized teacher-centered instruction in parallel to their epistemological beliefs, which contradicted with their PCK of argumentation. For example, Olivia held high-quality PCK of argumentation in all conceptions, but she lectured to cover the standards aligning with her beliefs about maximizing student learning.

The teachers' PCK and beliefs change over time as they engaged in professional development experiences (Park & Oliver, 2008; Schneider, 2013); but the change might be different for each teacher based on their prior experiences, background knowledge, beliefs, and contextual factors. According to Knight-Bardsley and McNeill (2016), each teacher held idiosyncratic nature of PCK, which was influenced by their previous knowledge, classroom practice, and reflection. The authors argued that the teachers should engage in explicit argumentation instruction and reflect on their practice to experience the change in their knowledge, beliefs, and practice. The teachers' enactment and reflection on what they did and what and how they know through professional development experiences could help them develop PCK of argumentation around student conceptions and instructional strategies.

The teachers in this study participated one-year PD program focusing on argumentation instruction, which was organized during the summer when the schools were closed. The professional development was not coupled with classroom instruction; but, the teachers were

encouraged to teach through argumentation instructional model during the academic year, and they were not required to reflect on their classroom instruction on each day of the implementation. Instead, in November 2017, they were required to participate a follow-up meeting to discuss the strengths and challenges of the implementation of ADI model. They also shared the samples of their students' work and lesson plans with other teachers for analysis and discussion. In parallel to Reiser (2013)'s suggestions for successful implementation of professional development, the teachers in this study were involved in active learning experiences with other teachers and experts and encouraged to apply and reflect on their knowledge, beliefs, and existing practice on each PD day to facilitate and maintain the change. They were also introduced to innovative instructional resources, learn how to develop activities, and to incorporate the educational technology into new curriculum materials and resources to promote argumentation instruction.

The results indicated that the teachers' enactment of argumentation instructional model after the PD program mediated by and resulted in improvements in their PCK of argumentation and epistemological beliefs. For example, Asia's evaluativist beliefs about nature of knowledge aligned with her high-quality PCK of argumentation for student conceptions. She had high-quality argumentation instruction that aligned with the argumentation instructional model as well as her PCK of argumentation and epistemological beliefs. Asia taught four argumentation activities aligned with the instructional model and had multiple opportunities to experience teaching the same activity with different age groups in her school context. The teacher also experienced reflection on her prior instructional decisions and practices to make revisions and incorporated discussions in parallel to her knowledge of NOS aspects. When Asia did not implement an ADI activity, she utilized traditional methods aligned with her epistemological beliefs including her beliefs about nature of knowing as an innate ability, utilizing textbook or

internet as the resource, and beliefs about maximizing student learning through teacher-centered approach.

The other three teachers, Bella, Eva, and Olivia, modified the argumentation instructional model in parallel to their epistemological beliefs. These teachers were unsuccessful in translating their PCK of argumentation; they preferred making modifications through combining or skipping the specific stages of the instructional model and promoting traditional instruction. These three teachers' lack of success in translating their PCK of argumentation into instruction linked to their insistence to cover the content or meet the standards through lecturing with pre-visual resources rather than enhancing the student-voice or dialogic discourse. These teachers focused on scaffolding the construction of arguments through explicit definitions of the structural components, sentence starters, and additional worksheets or integrating the aspects of ADI model into test preparation rather than promoting social interaction and social construction of knowledge claims. Bella did not experience teaching through ADI model throughout the year, but she asked students to cite evidence from the text while preparing students for standardized tests. Eva and Olivia experienced the positive change in their PCK of argumentation through teaching at least four ADI investigations and reflecting on their teaching experiences. They encouraged students to work in groups, but their classroom lacked the discourse practices as short responses received from students in the form of Triadic Dialogue and as the interactional pattern of a transmission focused type of science instruction in parallel with their multiplist beliefs about nature of knowledge and mixed beliefs about nature of knowing (González-Howard & McNeill, 2017).

The participants of this study either aligned or modified the argumentation instructional model in parallel to their PCK of argumentation and epistemological beliefs. These teachers

promoted low-quality argumentation instruction that they integrated one or two strategies, which could not facilitate argumentation in-depth. Low-quality argumentation instruction suggested that the teachers' multiplist epistemological beliefs mediated the translation of high-quality PCK of argumentation. The teachers' enactment of an argumentation instructional model also revealed their challenges for their enactment with fidelity in parallel to the results of previous studies. For instance, Asia and Bella had difficulty in teaching the argument structure- making the connection between data and evidence, generating justifications (McNeill et al., 2016; McNeill & Knight, 2013; Sampson & Blanchard, 2012). Eva referred to her challenge in promoting dialogic process through round robin and peer review process (Alozie et al., 2010; Gonzalez-Howard et al., 2017). Different from previous studies, this study also explicated the teachers' challenges in explaining the crosscutting concepts, addressing aspects of nature of science, asking rigorous questions, and defining the function of specific stages of the instructional model.

Professional development program focusing on the argumentation instructional model encouraged participants of this study to teach science as argument to promote students' engagement in scientific practices and develop conceptual understanding and nature of science conceptions. The teachers' sense-making, goals, and rationales for enacting the instructional model had an impact how they translated their PCK of argumentation consistent with the previous literature such as McNeill et al. (2017), Marco-Bujosa et al. (2017), and Knight-Bardsley and McNeill (2016). Two teachers, Asia and Eva, could translate their knowledge of NOS into practice while teaching argumentation consistent with the results of Capps and Crawford (2013) arguing the linearity among the teachers' knowledge and practice. This result was the evidence for how professional development supported the development of the teachers' PCK of argumentation, knowledge of NOS, and translation of their knowledge into practice.

However, consistent with results from Herman and colleagues (2013) and Wahbeh and Abd-El-Khalick (2014), Olivia and Bella's practices demonstrated the non-linearity between these teachers' knowledge of NOS and practices even though they engaged in argumentation instruction. These teachers' low-quality argumentation instruction linked to their mixed epistemological beliefs that mediated the translation of these teachers' PCK of argumentation into practice.

Factors Mediating the Argumentation Instruction

The study also examined the other factors that might mediate the argumentation instruction, in turn, influence the development of the science teachers' PCK of argumentation and epistemological beliefs as well as their translation into practice. The results indicated that the participating teachers possessed beliefs about student ability, district/standards, curriculum and testing, and school context as other factors influencing the argumentation instruction. In parallel to the results from Prime and Miranda (2006), the four in-service teachers addressed students' ability as mediating argumentation instruction involving process skills such as the ability to collect and analyze data, their prior knowledge such as lack of reading, writing or math skills, student characteristics including socioeconomic status or special learning needs, and attitudes such as motivation to learn science or behavior issues.

Marco-Bujosa and colleagues (2017) suggested that other contextual factors such as collaborating with other teachers in their school, administrative support, resources, and time might also mediate argumentation instruction. Consistent with these results, the teachers in the current study were concerned about lack of resources to incorporate argumentation activities into science instruction and time required to complete an ADI investigation as these teachers mostly needed at least five classroom hours to complete the stages of an ADI activity. Moreover,

McNeill and colleagues (2016) found that district policies, state standards, curriculum and testing requirements might mediate the implementation of argumentation in parallel to the results from the current study. However, there might be other factors mediating the argumentation instruction as well as development of PCK of argumentation and epistemological beliefs. For example, the teachers' learning goals for students and self-efficacy may influence the teachers' argumentation instruction and development of knowledge of student conceptions and instructional strategies (McNeill et al., 2016). Wahbeh and Abd-El-Khalick (2014) found that teachers' knowledge of science content, specific instructional strategies, student conceptions for argumentation, and the design and implementation of argumentation activities and resources might influence the development of teachers' PCK of argumentation and epistemological beliefs. Mesci and Schwartz (2017) also investigated the factors influencing the development of views of NOS as instructional, motivational, and sociocultural factors. Further research should explore what other factors may mediate the argumentation instruction and their influence on PCK of argumentation and epistemological beliefs.

Implications for Science Education and Future Research

This study explored the development of the teachers' PCK of argumentation and epistemological beliefs and how they translated their knowledge and beliefs into practice after a professional development program focusing on an argumentation instructional model (Argument-Driven Inquiry model). The teachers developed their PCK of argumentation and epistemological beliefs and used the instructional model in different ways based on their own understandings of the resources as well as their knowledge, beliefs, and context. Teachers need further support in how to interpret new instructional models and to use these models based on the suggestions from NGSS to develop knowledge of specific scientific practices such as

argumentation (Knight-Bardsley & McNeill, 2016). Teachers should move away from covering too much content like Reiser (2013) suggested, “to a focus on the in-depth development of core explanatory ideas” (p.1). Teachers should develop in-depth knowledge of core explanatory ideas through investigation and application in a coherent progression.

Further professional development efforts including the design of new instructional models, professional development programs, educative curriculum materials as well as teacher education programs should address in-service science teachers’ PCK of argumentation and epistemological beliefs in parallel to scientific practices in a coherent manner rather than as a separate activity. These efforts should support in-service science teachers of different grade levels with an explicit focus on teaching and learning through argumentation and about epistemology. Teachers should move away from addressing argumentation as a separate activity from other scientific practices (Berland et al., 2016). Instead, they should understand the coherency across different scientific practices and emphasize how these practices work together (Reiser, 2013). For example, the participating teachers’ experiences with the Argument-Driven Inquiry instructional model helped them learn how to promote meaningful argumentation through engaging in investigating a problem, collect and analyze data, construct evidence from the investigation, and build and refine conclusions in a coherent manner through collaborating as well as debating with others.

Teachers may need to apply what they have learned or experience the enactment of instructional models in their teaching context and reflect on the strengths and weaknesses of their practice with other teachers during the follow-up PD meetings. McNeill and Knight (2013) recommended that professional development programs should be designed considering “a situated view of knowledge” (p. 943) that provided teachers opportunity to design and apply an argumentation lesson, share the resources, and reflect on their implementation for revision.

Following these recommendations, this study suggests that more intensive interventions should aim to introduce new instructional approaches, help in-service science teachers analyze students' products, share their ideas with other teachers, and engage in explicit reflection on their knowledge, beliefs, and practice (Reiser, 2013). Teachers should be provided exemplar video cases of classroom practices to support them in analyzing students' scientific arguments and engaging in a debate such as exchanging ideas, critiquing and building off of each other's ideas (McNeill & Knight, 2013; Reiser, 2013).

A one-week summer professional development workshop at the beginning of the one-year PD program was limited to 30 hours. The teachers in this study also had opportunity to teach through argumentation instructional model in the real classroom during the academic year, and then to reflect on and discuss their teaching experiences to receive feedback from other teachers and professional development designers to make revisions. However, the literature suggested that sustained and intensive professional development programs involved "60+ hours support in the summer followed by 30 hours spread over the school year" (Reiser, 2013, p.13) and minimum two-year teaching experience necessary to result in significant changes in teachers' knowledge, beliefs, and practices (Osborne et al., 2013). Further research should explore the relationship between science teachers' PCK of argumentation, epistemological beliefs, and classroom instruction through longitudinal studies in different contexts. Longitudinal studies should be designed to provide opportunities for in-service teachers as well as science educators to work together in understanding and enacting new instructional models and reflecting on and revising science teachers' instructional practices.

More explicit attention should be given how teacher learning can be nurtured through conceptual change framework that teachers can experience a disequilibrium with their existing knowledge, beliefs, and practices, engage in new activities targeting their initial ideas, and reflect

on experience to revise their initial conceptions towards more plausible and fruitful conceptions (Bell et al., 2016; Posner et al., 1982; Vosniadou, 2003). In-service teachers should be supported to reflect on their PCK of argumentation, epistemological beliefs, and practices to explicitly discuss with other teachers, see alternative perspectives, and build on each other's ideas. Considering the results of this study, PD programs should be designed with conceptual change perspective to support in-service science teachers in recognizing and modifying their existing knowledge, beliefs, and practices towards developing more plausible and fruitful PCK of argumentation and epistemological beliefs.

Teacher education programs and research on science education should also support in-service teachers in developing sophisticated epistemological beliefs. The four teachers in the current study held consistently mixed or naïve views on certain aspects of NOS, experienced slight shifts from naïve to mixed views or from mixed to informed views or negative changes or recovered to their initial understandings by the end of the study. These results aligned with the findings of Posnanski (2010) and Donnelly and Argyle (2011). Posnanski (2010) provided the evidence for improved NOS understandings from naïve to more informed views through engaging in an activity-based environment including journal readings, scientific research techniques, and inquiry-based instruction in a two-year professional development program. Donnelly and Argyle (2011) also found that elementary, middle and high school teachers' participation in a physical science professional development graduate course addressing both decontextualized and contextualized NOS instruction resulted in improvements in the participating teachers' knowledge of certain aspects of NOS including *tentativeness*, *the distinction between theory and laws*, *empirical*, *creativity*, and *subjectivity* aspects. Further research should explore the changes in in-service teachers' knowledge of NOS aspects through longitudinal professional development programs focusing on both argumentation and NOS

instruction and should explore the reasons of why positive and negative shifts occur on certain aspects of NOS during the project.

Previous research (e.g., Capps & Crawford, 2013) also provided the empirical evidence for the linearity between knowledge of inquiry, knowledge of NOS, and instructional practices. Further studies should explore the relationship between in-service science teachers' PCK of argumentation and epistemological beliefs, particularly knowledge of NOS in detail. The results of this study also addressed the teachers' epistemological beliefs as domain-general and domain-specific epistemological beliefs that might mediate the translation of the teachers' PCK of argumentation into practice. In parallel to the suggestions from Deniz (2017), further research should examine the relationship between in-service teachers' beliefs about nature of knowledge and knowledge of aspects of NOS in detail. In other words, research studies should examine the relationship between science teachers' domain-general and domain-specific epistemological beliefs in large-scale studies in various contexts, and how science teachers' epistemological beliefs mediate their argumentation instruction.

An area of research suggests an examination of teachers' practical epistemologies in detail (Sandoval, 2005). In the current study, the science teachers' argumentation instruction as their practical epistemological should be considered as different from their formal epistemologies, which is their beliefs about how scientific knowledge is developed by professional scientists. Teachers need support in learning authentic scientific practices and questioning their existing understandings and perceptions of these practices, particularly argumentation. In parallel to suggestions from Sandoval (2005), future research designs should explore teachers' practical epistemologies through preparing interview protocols that will elicit their rationale for instructional decisions or approaches addressing argumentation instruction; video-cases or episodes will help to encourage teachers to interpret an episode from their own perspective about scientific

argumentation. The analysis of classroom discourse will help to understand whether teachers reflect on their epistemological beliefs while promoting scientific discourse.

Previous studies (Brownlee et al., 2011; Walker et al., 2012) argued that teachers might develop more sophisticated domain-general epistemological beliefs through one-semester or three-year professional development programs. Teachers might improve their beliefs about nature of knowledge and knowing on different dimensions such as beliefs about structure and integration of knowledge or beliefs about the speed of knowledge acquisition. However, the current study did not have a particular attention to investigating the teachers' beliefs about nature of knowledge and knowing on specific dimensions in detail. Further research should examine whether specific dimensions of in-service teachers' domain-general epistemological beliefs change through short or longitudinal interventions and what factors mediate the change in specific dimensions of domain-general epistemological beliefs.

This study also identified the factors that might influence the teachers' implementation of argumentation instructional model. Consistent with the literature, the study found that personal factors as the teachers' beliefs about student ability and external factors such as state standards, curriculum and testing, and school context mediated the argumentation instruction. Some teachers indicated that students' socioeconomic status might mediate their engagement in argumentation instruction. The teachers of the current study were teaching in urban schools, in which majority of students dealt with poverty issues that influenced their interest in science lessons and in learning through argumentation. Additional research should be conducted to explore how argumentation instruction might differ based on the urbanicity. There may be different factors that facilitate or hinder the argumentation instruction in different contexts. These factors require further investigation to examine why some teachers held traditional beliefs about teaching and learning science and resist to embrace research-based instructional approaches.

Lastly, the study did not examine how the teachers' PCK of argumentation and epistemological beliefs might influence students' learning outcomes. An area of research needs to focus on exploring the relationship between teachers' PCK of argumentation and epistemological beliefs and students' learning outcomes. In particular, how teachers' epistemological beliefs may influence their students' engagement in argumentation and epistemological beliefs.

Limitations

The results of this study applied to the four in-service urban science teachers, who were the purposeful participants of the study. First, the study was related to the teachers' implementation of the argumentation. The participating teachers were encouraged, but not required to integrate the argumentation instructional model into instruction that gave them flexibility about the enactment of the model. Three teachers in this study could teach at least four ADI investigations, but one teacher could not teach any ADI activity due to contextual factors. Second, the researcher attended the classroom observations during the second semester of the study when most of the teachers focused on preparing students for End-of-Class tests. The teachers were required to teach for the test by their administrators, which was a limitation of the study to observe an ADI activity; but, the researcher focused on whether the teacher promoted the use of structural or dialogic aspects of argumentation while preparing students for the test.

Third, the unit of the analysis of the current study was the teacher; each case was analyzed individually and then, the cross-case analysis was conducted. The researcher did not focus on collecting any student artifacts to promote the teachers' reflection on students' strengths and weaknesses in engaging in scientific argumentation and possible instructional strategies to accommodate student learning. Another data source for the study might be student-created artifacts to promote the teacher reflections on students' strengths and challenges in the use of scientific argumentation. Fourth, the study approached the teachers' domain-general epistemological beliefs

and their beliefs about teaching and learning science as stable and unchanged. The influence of the one-year PD program on the teachers' knowledge of NOS as domain-specific epistemological beliefs were explored. Further research should also explore whether in-service teachers change their domain-general and domain-specific epistemological beliefs through longitudinal studies with different research designs or methodologies targeting the development of teachers' epistemological beliefs. Fifth, the other factors mediating the argumentation instruction were specific to these four teachers even though they aligned with the previous studies. There might be other factors effective in other teachers' classrooms in different contexts that require further investigation.

Lastly, PCK of argumentation assessment included 16 multiple-choice items and four open-ended items, and the participants' responses were analyzed based on the accuracy of the responses to get quantitative scores on the teachers' knowledge of argument structure and dialogic process. The assessment instrument was appropriate to evaluate the teachers' PCK of argumentation based on numerical values for studies with larger sample size to apply quantitative data analysis methods. However, even though the participating teachers get low scores on the post1- and post2- PCK of argumentation assessments, their qualitative responses during the informal conversations or final interview provided in-depth data about their high-quality knowledge of argument structure or dialogic process as well as student conceptions for argumentation. This result suggested that assessing the PCK of argumentation through multiple-choice test might be a limitation to draw meaningful conclusions. Further studies should consider measuring science teachers' PCK of argumentation through assessment instrument followed by qualitative data sources such as interviews, essays, and reflections to gather in-depth data.

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APPENDICES

APPENDIX A

Argument-Driven Inquiry Instructional Model

Argument-Driven Inquiry (ADI) instructional model is an interdisciplinary activity designed with social constructivist theories of learning that involves individuals to construct what they know and understand through social interactions and their engagement in the practices of scientific community (Sampson et al., 2011; Schunk, 2016). ADI model addresses cognitive, social, and epistemic practices of science (Duschl, 2008; Sampson et al., 2011) and requires individuals to develop a method to collect and analyze data, communicate and justify the ideas with others, write investigation reports, share and document their work, and engage in peer review. These processes of science aim to help student construct scientific explanations, develop reasoning and critical thinking skills, understand the nature and development of scientific knowledge, improve communication skills, and develop scientific habits of mind including curiosity, skepticism, and openness to new ideas (Sampson & Grooms, 2010). The ADI instructional model has eight stages that can serve as a template to plan more authentic learning experiences in science classrooms. Figure 2 presents the stages of the ADI model, and detailed information about the stages is provided below⁸.

- 1) **Identification of Task:** The purpose of this stage is to introduce the major topic to be studied, initiate a laboratory experience to capture students' attention and interest to the topic. Teachers need to make connections between past and present learning experiences and emphasize the goal of the activity. In this stage, a teacher should provide a handout including brief introduction and researchable question and discuss the list of materials, hints, and suggestions. However, the teacher should not provide the possible answers of the research question and list of vocabulary terms to describe the content addressed in the lab and should not tell students that there was one correct answer of the research question.
- 2) **Designing a method and collecting data:** Students work in groups collaboratively (three or four students) while developing and implementing a method (for experiment, observation, investigation). They learn how to collect and analyze data, to deal with the ambiguities of the empirical work, and to ask questions such as "How do you know that your data is reliable? What else do you need to figure out? or Do you have enough data to support your ideas?" (Sampson & Gleim, 2009). The teacher needs to guide students about the data they get from the design. Students have opportunity to engage in "guided inquiry" and interact with competing claims (Sampson & Grooms, 2010; Walker & Sampson, 2012). The teacher should not directly provide a procedure to follow and approve the incomplete investigation proposals.
- 3) **Data analysis and development of a tentative argument:** In this stage, students make sense of their measurements or observations, analyze and interpret their data, and produce a tentative argument including a claim, evidence, and reasoning on a large whiteboard. The teacher reminds students

⁸ The information about the stages of the ADI model was summarized from Sampson et al. (2011), Walker and Sampson (2012), Sampson et al. (2013), and Grooms et al. (2016).

about the research question and requires the construction of an argument with an answer to the question supported by an appropriate evidence and related scientific principles. In this stage, the teacher should guide students to work collaboratively and interact with each other rather than focusing on the right answer and receiving the answer only from one student.

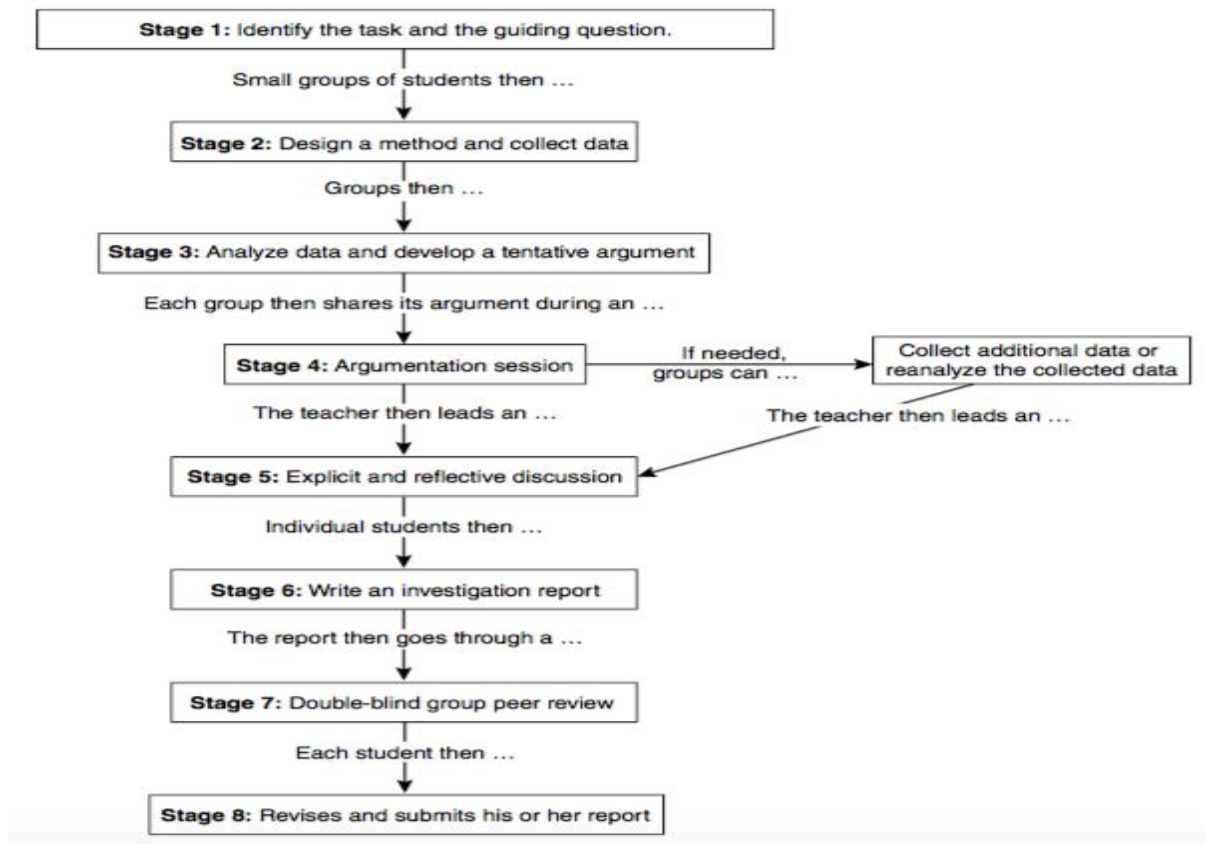
- 4) **Argumentation Session:** In this stage, small group works of students share their arguments with other groups to critique the work of others or arguments, to be exposed to others' ideas or alternative claims to determine the validity of each other's claims or arguments and revise. Students have opportunity to collaborate with their peers and provide feedback on the quality of each other's arguments. The teacher should remind students about the appropriate behaviors of the learning community, encourage students to ask questions, and use the appropriate empirical and theoretical criteria. The teacher should encourage students to respond positively, ask questions, and discuss ideas supported by evidence. ADI model suggests teachers to use "gallery walk" or "round robin" format rather than a whole-class presentation. Gallery walk is defined as "one or two members of the group stay at their workstation to share their groups' ideas, while the other group members go one at a time to different groups to listen to and critique the arguments developed by their classmates" (Grooms, Enderle, Hutner, Murphy, & Sampson, 2016, p. 10). Students should keep the records of the critiques and the ways to improve their arguments in this session. In this session, the teacher aims to encourage students to think about what and how they know and why some claims are more valid than others in science. The teacher should also be involved in the discussions and ask questions such as "How did you analyze the available data? Were there any data that did not fit with your claim?" or the teacher should encourage students to ask "Do you think their analysis is accurate? Do you think their interpretation is sound? Do you think their claims fit with what we know about X?" (Grooms et al., 2016).
- 5) **Explicit and Reflective Discussion:** In this stage, the teacher encourages students to discuss what they have learned about the content, how they know what they know, the nature of science and the areas that they need to improve next time. The teacher should not provide a lecture and skip the discussion of nature of science and scientific inquiry. The teacher should ensure that students can understand the main ideas about the content and crosscutting concepts and engage in scientific practices through planning and carrying out investigations, analyzing and interpreting data, and arguing from evidence (Grooms et al., 2016). The teacher should also provide opportunity for students to reflect on what students have done, how they collected, analyzed, and interpreted data, and how they argued from evidence, and how they can improve the investigation next time. The teacher should ask students about the strengths and weaknesses of their investigation and how to address these weaknesses to improve their investigation.
- 6) **Writing the Investigation Report:** Writing aspect of the ADI model aims to promote students' understanding of science content, make their thinking visible, and encourage metacognition (Sampson & Grooms, 2010). This stage encourages students to share the results of their research through writing in a reflective manner through the standards and norms of the scientific community. The ADI model encourages students to write an investigation report addressing three main questions: "What were you trying to do and why? What did you do, and why? What is your argument?" (Walker & Sampson, 2012). The teacher should remind students about the audience,

topic, purpose of the report, and how to provide feedback and explain the peer review guide and the samples of investigation reports. The teacher should also encourage students to use tables and graphs to organize the evidence and include reference information in the investigation report. The report should be limited to one single-spaced page.

- 7) Double-blind review: After completing the writing process, students prepare three copies of their investigation reports for peer review without any identification information. Students use the peer review sheets to evaluate the quality of an investigation and provide feedback to the author. The peer review sheet included questions such as “Did the author make the research question and/or goals of the investigation explicit? Did the author describe how they went about his or her work? Did the author use genuine evidence to support their explanation? Is the author’s reasoning sufficient and appropriate?” (Sampson et al., 2011). Each person or group provides review on each report based on the criteria on the peer review sheet.
- 8) Revision and submission of the investigation report: In this stage, students need to edit their investigation reports based on the reviewers’ comments or respond to reviewers’ comments. Students should explain what they did based on reviewers’ comments on the peer review sheet.

Figure 2

Stages of ADI model



APPENDIX B

PROFESSIONAL DEVELOPMENT PROGRAM

The professional development program held in five days, approximately 30 hours during the summer, 2016, continued with a one-day follow-up meeting during the fall semester, and ended with a final interview at the end of Spring 2017.

Day- 1	Morning: 1. Introduction & Paperwork 2. Evaluation Data Collection 3. Overview of ADI Instructional Model 4. Begin ADI #1	The professional development program started with an introduction and data collection including the assessment of participants' prior PCK of argumentation and knowledge of NOS with PCK of argumentation assessment and VNOS-270 questionnaires, respectively. Then, the professional development designers provided an overview of argumentation instructional model, Argument-Driven Inquiry (ADI) model through seeking for the answers of the following questions: • What is argumentation? • Why is argumentation important in science? • Why is argumentation important in science classrooms? • How is argumentation beneficial to student learning? • What is involved in scientific argumentation? • Considerations for the science classrooms • Brief description of instructional models on argumentation
	Lunch – Journaling questions	The teachers write their reflections on the following questions: 1. How would you describe argumentation as it relates to the science classroom? 2. What experiences have you had with teaching using argumentation in your classroom? 3. What do you feel are the greatest challenges to teaching using argumentation in your classroom? 4. What are your greatest challenges in teaching argumentation?
	Afternoon: 1. Finish ADI #1 (Stages 1-4) Argumentation Session 2. Stage 5 Discussion with Dr. A & Dr. B 3. Teachers write Investigation Report	The participating teachers had a chance to engage in the first ADI investigation. During the Explicit and Reflective Discussion session, the teachers had discussions with two professors on physics concepts and nature of science and scientific inquiry. Then, they started writing the investigation report.

Day- 2	Morning: 1. Peer Review Session for ADI #1 2. Nature of Science & Crosscutting Concept Discussion with Dr. B	On the second day, the teachers started the peer review of the investigation reports. After they completed the peer review, revised and resubmitted the investigation reports, they had discussions with a professor on nature of science and crosscutting concepts related to ADI investigation.
	Lunch –Journaling Questions	The teachers write their reflections on the following questions: 1. How familiar have you been with Nature of Science (NOS) concepts before today’s session? How much have you focused on them explicitly in your science teaching? 2. Do you feel it is important for your students to learn about NOS concepts? Why or why not? 3. How do you think using argumentation in your science classroom can help your students learn about NOS concepts?
	Afternoon: 1. ADI #2 (Stages 1-4) 2. Stage 5 Discussion with Dr. A & Dr. B	The participating teachers started the second ADI investigation. During the Explicit and Reflective Discussion session, the teachers had discussions with professors on physics concepts and nature of science and scientific inquiry.
Day- 3	Morning: 1. ADI #3 (Stages 1-4) 2. Stage 5 Discussion with Dr. A & Dr. B 3. Review Student Reports	The participating teachers started the third ADI investigation. During the Explicit and Reflective Discussion session, the teachers had discussions with two professors on physics concepts and nature of science and scientific inquiry. They also started to analyze students’ arguments on student created investigation reports.
	Lunch –Journaling	No journaling
	Afternoon: 1. ADI #4 (Stages 1-4) 2. Stage 5 Discussion with Dr. A & Dr. B 3. Review Student Reports	The participating teachers started the fourth ADI investigation. During the Explicit and Reflective Discussion session, the teachers had discussions with two professors on physics concepts and nature of science and scientific inquiry. They also analyzed students’ arguments on student created investigation reports.
Day-4	Morning: 1. Discussion about Assessing Discourse with Dr. C 2. ADI #5 (Stages 1-4)	The participating teachers had discussions with a professor on how to assess discourse during the science instruction. Then, they started the fifth ADI investigation and completed the first four stages.
	Lunch –Journaling	The teachers write their reflections on the following questions: 1. What is evidence? What makes evidence high quality?

		2. What is justification? What makes a justification high quality? 3. What kinds of evidence do you expect from your students? Do you think some types of evidence are better than others? Explain your reasoning. 4. What kind of support do you think your students will need to help understand evidence and justification?
	Afternoon: 1. Stage 5 Discussion with Dr. A & Dr. B 2. Review Videos of Student Discourse	During the Explicit and Reflective Discussion session, the teachers had discussions with two professors on physics concepts and nature of science and scientific inquiry. They also analyzed students' oral arguments from videos of classroom discourse.
Day-5	Morning: 1. ADI #6 (Stages 1-4) 2. Stage 5 Discussion with Dr. A & Dr. B	The participating teachers started the sixth ADI investigation. During the Explicit and Reflective Discussion session, the teachers had discussions with two professors on physics concepts and nature of science and scientific inquiry.
	Lunch –Journaling	The teachers write their reflections on the following questions: 1. How prepared do you feel to teach the investigations you experienced this week? 2. Do you feel your students will be able to productively engage with these investigations? 3. What challenges do you think your students will have with designing and conducting investigations? 4. What challenges do you think your students will have with engaging in verbal and written argumentation? 5. What kinds of support do you think you will need to provide to your students with these investigations?
	Afternoon: 1. Review of Student Reports 2. Tips & Tricks Presentation by Dr. C 3. Evaluation-Data Collection	The teachers analyzed students' arguments on student created investigation reports. Then, professional development designers provided the "Tips & Tricks" to use during the instruction. At the end of the program, the teachers were asked to complete the second PCK of argumentation assessment and VNOS-270 questionnaires to assess the influence of PD program on the teachers' PCK of argumentation and knowledge of NOS.
Follow-up meeting (Fall, 2016)	Morning: 1. Teacher Discussion of Challenges and Benefits for ADI 2. Review of Student Work from Teachers' Classrooms	The participants engaged in discussion on their challenges and strengths in the implementation of ADI model. They also shared the samples of their own students' work with other teachers for analysis and discussion.

	Afternoon: 1. Review of Upcoming Physical Science Content with Dr. A 2. Lesson Plan Review for Upcoming ADIs	The participants had discussions with a physics professor on how to teach physics concepts of upcoming ADI investigations. They also shared the lesson plans with other teachers for review and discussion.
The teachers were asked to complete the third PCK of argumentation assessment and VNOS-270 questionnaires to assess the influence of PD program and argumentation instruction on teachers' PCK of argumentation and knowledge of NOS (at the end of Spring 2017).		
Final Interview (at the end of Spring 2017): The teachers reflected on their PCK of argumentation, knowledge of NOS, and implementation of ADI model during the interview. The researcher aimed to ask some clarification questions to participants responses on the pre-, post1-, post2- PCK of argumentation assessment and VNOS-270.		

APPENDIX C

PCK of Argumentation Assessment

This is the final revised version that includes 4 vignettes. Mr. Cedillo:

Mr. Cedillo's 7th grade science class is doing a unit on force and motion. Near the middle of the unit his students are exploring friction by analyzing the data table from an investigation they conducted that answered the question: Which type of surface material will allow a toy car to have the greatest average speed? The students let a toy car go from the top of a ramp and timed how long it took to travel 1 meter after reaching the bottom of the ramp, over four different surface materials: felt, top of lab table, sand paper, and ice (see image below).

Toy car



They then calculated the toy car's average speed by dividing the distance over the time. The table below shows the students' experimental results.

Surface Material	Distance Traveled (meters)	Time (seconds)	Average Speed (meters/seconds)
Felt	1.0	2.4	0.42
Top of lab table	1.0	1.5	0.67
Sand paper	1.0	2.2	0.45
Ice	1.0	1.0	1.0

Ellen raises her hand in class and states the following argument: The car on the ice will always go the fastest. I've been in a car driving on ice, and I know a car can skid because ice is the smoothest surface. My dad has a really big truck and it doesn't slide as far, so maybe next time we should try this experiment with larger cars.

1. Mr. Cedillo should respond by saying:
 - a. "Interesting point, Ellen. Does anyone have similar reasoning?"
 - b. "Great connection. Can anyone suggest data to support this?"
 - c. "Nice argument. What additional evidence could Ellen add?"
 - d. "Well done. Does anyone else want to share their argument?"

Mr. Cedillo next asks his students to engage in an oral argument, during which they debate their ideas about the relationship between surface material and average speed. The excerpt below is from the beginning of their conversation.

Maya: My claim is that rough materials cause cars to go faster.

Elana: I think the data table shows that rough materials make cars go slower.

Ben: Well, I think there are lots of reasons a car would go faster or slower.

Mr. Cedillo should speak up and encourage his students to:

- a. Debate other possible reasons a car might go faster or slower
- b. Focus the class discussion on the scientifically accurate claim
- c. Research and include what expert scientists say about friction
- d. Convince their fellow classmates that their claim is the best

After Mr. Cedillo intervenes, Elizabeth speaks.

Elizabeth: I think the surfaces with more friction caused the cars to slow down sooner. This means that they will take longer to go 1 meter. Friction is when two surfaces rub against each other creating a force in the opposite direction an object is moving. Something has more friction when it is rougher.

2. Elizabeth:

- a. Should explain her argument's relevant science concept
- b. Needs to incorporate evidence to support her claim
- c. Requires help stating an accurate claim about the surfaces
- d. Does not require any modifications to her argument

For homework, Mr. Cedillo asks the students to write out their arguments. Gustavo writes the following argument: Our car went the fastest on ice also. It had a speed of 1.0 meters per second. This was faster than the felt, where the car averaged 0.42 meters per second. This is because of friction.

3. Mr. Cedillo should say to Gustavo:

- a. "Describe how you calculated the speed of the toy car."
- b. "Identify scientific principles that link to your claim."
- c. "Clarify how the evidence connects to your claim."
- d. "This argument looks good, no further work needed."

4. What are two strategies that you believe are effective for helping students **engage in oral argumentation**? Explain your rationale for why you believe these strategies are effective.

Mr. Luongo:

Mr. Luongo asked his students to read an article and construct a scientific argument about whether *Elysia chlorotica*, a unique species of sea slug, should be characterized as a plant or animal. The article described the ways in which the slug exhibits characteristics of both plants, such as performing photosynthesis, and animals, such as being heterotrophs. Two of his students' written arguments are provided below:

Beatriz: I think that *Elysia chlorotica* should be classified as plants. The article we read said that these slugs eat algae and once they eat those algae they have the genes for performing photosynthesis. That's why I think that *Elysia chlorotica* should be considered a plant more than an animal.

Joao: I think that the green sea slugs *Elysia chlorotica* should be considered animals. I've seen slugs when I play in the park and I know that they move and eat like other animals do. Plants are autotrophs, which means they make their own food. Animals are heterotrophs, which means that they need to eat other things to live.

After reading these students' responses, Mr. Luongo should:

- a. Tell students to critique each other's arguments about the sea slug's classification
- b. Encourage students to read more about distinguishing between plants and animals
- c. Remind students that personal observations do not count as evidence for a claim
- d. Have students analyze a scientific video that explains why this sea slug is an animal

Mr. Luongo gives the students an opportunity to edit their arguments. Beatriz adds the following sentences to her argument: I remember learning earlier this year that plants, like trees and lily pads, perform photosynthesis. So if this slug does photosynthesis it must be a plant.

1. By adding these sentences, Beatriz
 - a. Used appropriate evidence to support her claim
 - b. Weakened the claim she made in her argument
 - c. Explained why the evidence supported the claim
 - d. Incorporated a more scientifically accurate claim

Mr. Luongo then pairs up students to edit each other's arguments. While walking around the room he hears the following interaction:

Leah: Claire, you wrote that this slug becomes a plant after eating algae? You're using X-men to support your claim?

Claire: Yeah! Remember the character Rogue? She takes other mutants' powers and this slug basically does the same with algae—after eating algae it can do photosynthesis. So like Rogue this slug becomes what it takes in, in this case a plant.

Leah: Oh I guess you're right. I should add that as more supporting evidence for my claim too!

2. After hearing these students' conversation Mr. Luongo should:
 - a. Prompt students to review the class description of what counts as evidence
 - b. Encourage students to explain the scientific reasoning behind this evidence
 - c. Remind students to incorporate as many pieces of evidence as possible
 - d. Have students consider how this evidence could support the counter claim

Daniela writes the following argument to share with her small group: *Elysia chlorotica* could be either a plant or an animal. Sam thought *Elysia chlorotica* could be an animal because it eats

other organisms. Animals get their energy from consuming other species. But Jan thought it could be a plant because it performs photosynthesis. Photosynthesis allows plants and algae to use energy from the sun to create sugar.

4. Daniela needs help:
 - a. Including scientific reasoning in her written argument
 - b. Critiquing alternative explanations about this species
 - c. Understanding how photosynthesis occurs in organisms
 - d. Distinguishing between plant and animal characteristics
5. What do you think are the benefits and drawbacks to Mr. Luongo's approach of having students debate a topic with multiple claims? Explain.

Ms. Strong:

Ms. Strong's students are preparing for a science seminar in which they will engage in oral argumentation to consider whether or not humans could survive in settlements on Mars. Before taking part in the science seminar, the students compile the following pieces of information onto a large poster to display in the front of the room:

Similarities Between Earth and Mars	Differences Between Earth and Mars
▪ Mars has seasons much like Earth, though they last nearly twice as long because the Martian year is about 1.88 Earth years ▪ The Martian day is very close in duration to Earth's ▪ Recent observations by NASA confirmed the presence of frozen water on Mars	▪ Mars is much colder than Earth. It can get to a low of -104 degrees Celsius. The lowest temperature ever recorded on Earth was -89.2 degrees Celsius in Antarctica ▪ There are no bodies of liquid water on the surface of Mars ▪ Mars' atmosphere contains more carbon monoxide than the Earth's atmosphere

To get her students ready for the science seminar, Ms. Strong has them use the table to write arguments. Alicia and Thomas write the following arguments:

Alicia: I don't think humans can survive on Mars. The chart shows that Mars can get much colder than Earth and I saw a show on the Discovery Channel about the special clothes scientists have to wear when they do experiments in Antarctica because of the cold. It would be really awful to wear these clothes all the time just to go outside and it would cost a lot of money to get everyone these clothes.

Thomas: I think that settling on Mars would be great for humans. Days on Mars and Earth are almost the same length so we wouldn't have to change watches and clocks. Mars also has seasons like Earth so we'd have those too but they'd just be twice as long. Imagine how long summer break would be! No school for almost six months. Awesome.

1. What are the strengths and weaknesses of how Alicia explains why her evidence supports her claim? Why?
2. After reading Alicia and Thomas' responses, Ms. Strong should begin by:
 - a. Having students collect more numerical data about the planets under study
 - b. Telling students to critique each other's claims about human survival on Mars
 - c. Asking students to analyze their current understanding of the scientific topic
 - d. Encouraging students to organize the evidence in the table with a Venn Diagram

After writing arguments, Ms. Strong's students engage in the science seminar. During the discussion the following exchange takes place:

Alex: I think we could live on Mars. It would be awesome!

Melanie: My claim is the opposite of Alex's. I don't think that humans could live on Mars.

Alex: Why not? What's your evidence?

Melanie: Well there aren't any bodies of water on Mars' surface and humans need water to live.

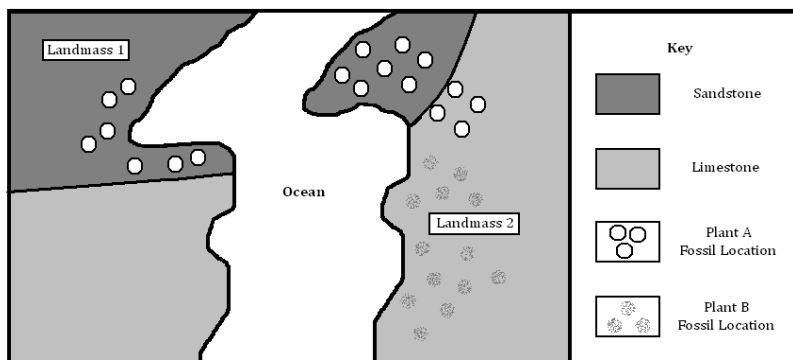
Tina: There might not be lakes and oceans on Mars like there are here on Earth, but I still agree with Alex because NASA scientists saw frozen water on Mars so humans could use that to live.

Melanie: Yeah, but how much water did they find? Did they measure how much there is?

3. What could have Ms. Strong said before beginning this science seminar to encourage Melanie, Alex and Tina to have this type of discussion?
 - a. "The purpose behind a science seminar is for everyone to share their ideas."
 - b. "The objective of a scientific argument is to use all the evidence in the data table."
 - c. "The point of this seminar is to make sure we all understand your argument."
 - d. "The goal of argumentation is to convince each other of the strength of a claim."
3. By having students engage in a science seminar, Ms. Strong's main goal is to help students:
 - a. Develop more interest in the seminar topic
 - b. Generate accurate answers to the question
 - c. Evaluate their classmates' different claims
 - d. Practice sharing out ideas with their peers
4. Later in the science seminar Justin says, "Humans couldn't live on Mars because its atmosphere has carbon monoxide. If no other students respond, after an appropriate wait time, Ms. Strong should say:
 - a. "Explain how the data supports your claim"
 - b. "What are some key elements of a strong claim?"
 - c. "We need some quantitative data for this idea"
 - d. "What gasses can we find in the atmosphere?"

Ms. Alves:

Ms. Alves' 6th grade science class is near the end of a unit about plate tectonics. She gives her students the following diagram.



She then asks them to write scientific arguments answering the question: Do you think these two land masses have always been in the same location or do you think they were once in different locations? Before writing their arguments, Ms. Alves has the students turn and talk with a partner. She hears Sofia say the following: “I think these two landmasses were not always in the same location. They were probably connected without any ocean between them. I mean, look at the shapes of the masses. They look like they once fit into each other, like a puzzle. And remember how last week we read about Pangaea and how there used to be one big supercontinent on Earth?”

What are the strengths and the weaknesses of the evidence Sofia uses in her argument? Explain.

Sofia's argument:

- Needs a more complete claim about the movement of the landmasses
- Should include quantitative evidence so that it will be more convincing
- Lacks an explanation of how the science concept supports her answer
- Contains an accurate rebuttal that is relevant to the landmass diagram

After writing their arguments, Ms. Alves groups students with opposing claims together and asks them to provide each other with constructive feedback. Ms. Alves notices that students are not critiquing each other's arguments.

- Which of the following strategies would help her students do so?
 - Have each student use a rubric to evaluate their own scientific argument
 - Model what counts as appropriate high-quality evidence for the strongest claim
 - Do a mini-lesson to demonstrate how to write a convincing scientific argument
 - Show the students a video of a scientist questioning another scientist's claim

While monitoring students' discussions about their arguments, Ms. Alves hears Nora, Lucas and Maxwell have the following conversation:

Maxwell: Well, I wrote that I think these two landmasses were always in the same location.

Nora: I don't agree with you. I think they were once connected and then moved apart over millions of years. Just look at the landmass' shapes. They obviously once went together.

Maxwell: Maybe, but what about the other pieces of evidence, like the fossils? What do you think Lucas?

Lucas: I'm not sure. What if an asteroid hit the Earth and caused the ocean to form there?

3. Ms. Alves should consider the start of this argumentation discussion to be:
 - a. Unsuccessful because the students didn't address all the possible pieces of evidence
 - b. Unsuccessful because Lucas does not have a chance to share a claim with his peers
 - c. Successful because students are trying to convince each other of the strongest claim
 - d. Successful because Lucas introduced additional evidence about asteroids at the end

The students' conversation continues:

Maxwell: Nora you only mentioned one of the fossils from the picture but not all of the plant fossils are on both landmasses. "Plant A" fossils are on both, but the "Plant B" ones are only on Landmass 2.

Nora: So what? That doesn't mean I'm wrong. Both plants didn't necessarily grow before they separated. Maybe "Plant B" grew after the landmasses had already separated.

Maxwell: I don't agree. I think all of the plant fossils were from the same time.

4. One reason that Ms. Alves should consider this a successful argumentation interaction between Maxwell and Nora is:
 - a. Nora and Maxwell displayed in depth fossil knowledge
 - b. Maxwell demonstrated that he will stand by his claim
 - c. Maxwell and Nora discussed only high-quality evidence
 - d. Nora incorporated new evidence into her argument

APPENDIX D

Epistemological Belief Survey

Please indicate how strongly you agree or disagree with each of the statements listed below.
Please circle the number that best corresponds to the strength of your belief.

1. You can believe most things you read.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

2. The only thing that is certain is uncertainty itself.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

3. If something can be learned, it will be learned immediately.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

4. I like information to be presented in a straightforward fashion; I don't like having to read
between the lines.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

5. It is difficult to learn from a textbook unless you start at the beginning and master one section at a time.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

6. Forming your own ideas is more important than learning what the textbooks say.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

7. Almost all the information you can understand from a textbook you will get during the first reading.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

8. A really good way to understand a textbook is to reorganize the information according to your own personal scheme.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

9. If scientists try hard enough, they can find the answer to almost every question.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

10. You should evaluate the accuracy of information in textbooks if you are familiar with the topic.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

11. You will just get confused if you try to integrate new ideas in a textbook with knowledge you already have about a topic.

strongly disagree	disagree	unsure	agree	strongly agree

12. When I study, I look for specific facts.

strongly disagree	disagree	unsure	agree	strongly agree

1	2	3	4	5

13. If professors would stick more to the facts and do less theorizing, one could get more out of college.

strongly disagree	disagree	unsure	agree	strongly agree

1	2	3	4	5

14. Being a good student generally involves memorizing a lot of facts.

strongly disagree	disagree	unsure	agree	strongly agree

1	2	3	4	5

15. Wisdom is not knowing the answers, but knowing how to find the answers.

strongly disagree	disagree	unsure	agree	strongly agree

1	2	3	4	5

16. Working on a difficult problem for an extended period of time only pays off for really smart students.

strongly disagree	disagree	unsure	agree	strongly agree

1	2	3	4	5

17. Some people are born good learners; others are just stuck with a limited ability.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

18. Usually, if you are ever going to understand something, it will make sense to you the first time.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

19. Successful students understand things quickly.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

20. Today's facts may be tomorrow's fiction.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

21. I really appreciate instructors who organize their lectures carefully and then stick to their plan.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

22. The most important part of scientific work is original thinking.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

23. Even advice from experts should be questioned.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

24. If I can't understand something quickly, it usually means I will never understand it.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

25. I try my best to combine information across chapters or even across classes.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

26. I don't like movies that don't have a clear-cut ending.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

27. Scientists can ultimately get to the truth.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

28. It's a waste of time to work on problems that have no possibility of coming out with a clear-cut answer.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

29. Understanding main ideas is easy for good students.

strongly disagree	disagree	unsure	agree	strongly agree

1	2	3	4	5

30. It is annoying to listen to lecturers who cannot seem to make their mind up as to what they really believe.

strongly disagree	disagree	unsure	agree	strongly agree

1	2	3	4	5

31. A good teacher's job is to keep students from wandering from the right track.

strongly disagree	disagree	unsure	agree	strongly agree

1	2	3	4	5

32. A sentence has little meaning unless you know the situation in which it was spoken.

strongly disagree	disagree	unsure	agree	strongly agree

1	2	3	4	5

33. The best thing about science courses is that most problems have only one right answer.

strongly disagree	disagree	unsure	agree	strongly agree

1	2	3	4	5

34. Most words have one clear meaning.

strongly disagree	disagree	unsure	agree	strongly agree

1	2	3	4	5

35. The really smart students don't have to work hard to do well in school.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

36. When I learn, I prefer to make things, as simple as possible.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

37. I find it refreshing to think about issues that experts can't agree on.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

38. The information we learn in school is certain and unchanging.

strongly disagree	disagree	unsure	agree	strongly agree
1	2	3	4	5

APPENDIX E

VNOS-270

Name: _____

Date: _____

- You have had years of experiences with science, in the classroom and in real life. This survey asks you to think about science and describe your ideas. There are no right or wrong answers, as these are simply your ideas at this time. Please respond as completely as you can. **You can use as much space as you need.**
 - Some questions have more than one part. Please make sure you write your answers to each part.
 - This survey is NOT an evaluation of you. You will not be graded or judged based on your answers. The ExpeRTS program is designed to help you think about these topics, and so we need to know where you begin.
1. What, in your view, is **science**? How can you determine when something **is** science (such as biology or physics) and when something is **not** science (such as religion or philosophy)?
 2. How are science and art similar? How are they different?
 3. Scientists agree that about 65 millions of years ago the dinosaurs became extinct. However, scientists still disagree about what caused this extinction.
 - (a) Why do you think they disagree even though they all have the same information?
 - (b) Do you think this controversy could be resolved? If so, how? If not, why not?
 - (c) How do you think scientists know how dinosaurs looked and moved?
 4. There are many types of phenomena (past, present, and future) that scientists study, but cannot see. For example, scientists have never seen “dark matter”, the center of the earth, or into the nucleus of an atom. Yet many scientists use their understanding of these phenomena to do research.
 - (a) If they have never seen these things, what kind of information do scientists use to figure out these things exist or what they look like?
 - (b) Should we, as a public, accept scientists’ explanations or descriptions of things they have not seen? Why or why not?
- Scientists try to find answers to their questions by doing investigations. Do you think that scientists use their imagination & creativity in their investigations?
- (a) If you think “YES”, explain why and in what part of their investigations (planning, analysis of data, interpretation, etc.) you think they use their imagination & creativity
 - (b) If you think “NO”, explain why imagination & creativity are not part of science.
6. (a) What do you think is the difference between a scientific theory and a scientific law?

A scientific theory is ...

A scientific law is ...

(b) Give an example of a scientific theory and an example of a scientific law.

Example of a Scientific Theory: _____

This is a theory because ...

Example of a Scientific Law: _____

This is a law because ...

(c) Do you think scientific theories we have today will change in the future? Why or why not?

(d) Do you think scientific laws we have today will change in the future? Why or why not?

7. Some claim that science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that science is universal. That is, science transcends national and cultural boundaries and is not affected by social, political, and philosophical values, and intellectual norms of the culture in which it is practiced.

- If you believe that science reflects social and cultural values, explain why and how. Defend your answer with examples.
- If you believe that science is universal, explain why and how. Defend your answer with examples.

APPENDIX F

Day 1:

5. How would you describe argumentation as it relates to the science classroom?
6. What experiences have you had with teaching using argumentation in your classroom?
7. What do you feel are the greatest challenges to teaching using argumentation in your classroom?
8. What are your greatest challenges in teaching argumentation?

Day 2:

4. How familiar have you been with Nature of Science (NOS) concepts before today's session? How much have you focused on them explicitly in your science teaching?
5. Do you feel it is important for your students to learn about NOS concepts? Why or why not?
6. How do you think using argumentation in your science classroom can help your students learn about NOS concepts?

Day 4:

5. What is evidence? What makes evidence high quality?
6. What is justification? What makes a justification high quality?
7. What kinds of evidence do you expect from your students? Do you think some types of evidence are better than others? Explain your reasoning.
8. What kind of support do you think your students will need to help understand evidence and justification?

Day 5:

6. How prepared do you feel to teach the investigations you experienced this week?
7. Do you feel your students will be able to productively engage with these investigations?
8. What challenges do you think your students will have with designing and conducting investigations?
9. What challenges do you think your students will have with engaging in verbal and written argumentation?
10. What kinds of support do you think you will need to provide to your students with these investigations?

APPENDIX G

Questions Guiding to Informal Conversations

The informal conversations are guided by the following sample questions to understand teachers' thinking and experiences of the implementation of teaching and learning science, particularly, argumentation instruction (modified from published literature such as Luft & Roehrig (2007); Tsai (2008)):

1. How many ADI activities have you taught so far? Could you please tell us about the process of implementation of ADI activities?
2. What is your overall impression of how successful the implementation of argumentation was in aiding your students' learning? What was the most successful moment for students' learning during the instruction? Why?
3. Do you feel your students improved in their ability to engage in scientific argumentation, both verbal and written? Why or why not?
4. What major challenges did you experience with implementing argumentation?
5. What is your role as a science teacher? What do you think are the most important things to emphasize in your teaching? Why?
6. How does learning occur? How do students learn science best?
7. What will you do differently next time you implement argumentation or teach any argumentation lesson?
8. Do you feel you have improved your ability to teach using scientific argumentation? Why or why not?
9. What are the main characteristics of scientific knowledge? What makes science different from other disciplines of inquiry?
10. How do you address the aspects of nature of science during the instruction? Could you provide specific example?

APPENDIX H

Final Interview Questions

Sample questions asked during the final interview:

1. What is science? What would make something not science? What are the particular aspects of science that process of science that are unique?
2. How do scientists come to a consensus?
3. How do you explain theory and law to your students? What kind of definition do you give them for those? How do scientific theories and laws change?
4. How does scientists with the same information interpret it differently? What differences cause different interpretations?
5. How do we evaluate certainty? How do you think scientists evaluate certainty?
6. How are the theories, models and laws that scientists rely on? How does that play a role in determining the quality of evidence?
7. How do you support your students when they are engaged in verbal argumentation?
8. How do you help students deal with competing claims? How do you help them, again, not necessarily resolve, but perhaps come to a consensus in some way? What do you do?
9. How do you help your students learn how to evaluate the quality of evidence? What are some indicators of high-quality or low-quality evidence for you?
10. How do you support students to listen and build off each other's ideas? Does that something naturally occur or are there ways that you can facilitate that?
11. How do you help students understand how to critique? What do you think has to happen to help them understand what is appropriate critique and what is not appropriate critique in those situations?
12. What do you think is the most valuable aspect of participating in the professional development program?

APPENDIX I

NOS Continuum

Tentativeness	←-----→ - (+) + ++ +++
Creativity	←-----→ - (+) + ++ +++
Subjectivity	←-----→ - (+) + ++ +++
Observation/inference	←-----→ - (+) + ++ +++
Empirical	←-----→ - (+) + ++ +++
Theory/law	←-----→ - (+) + ++ +++
Socio/cultural	←-----→ - (+) + ++ +++
Methods	←-----→ - (+) + ++ +++

APPENDIX J

Observation Schedule

Chronological order of the classroom observations for each teacher (the data collection was specified as observation, informal conversation, or both).

Asia	Bella	Eva	Olivia
(Both Observation, Informal conversation) March 14, March 16, March 19, March 21, March 22, March 23, March 24, March 27, March 28, May 10, May 12, May 15, May 16, May 17, May 18 (Observation) May 9, May 19 (Informal conversation) May 3, May 31	(Both Observation, Informal conversation) April 11, April 13, April 17, April 19, April 21, May 11, May 15, May 17, May 23 (Informal conversation) May 25	(Both Observation, Informal conversation) March 7, March 16, March 20, March 21, March 22, March 23, March 29, April 10, April 12, April 14, April 18, April 20, April 24, April 27 (Observation) March 6, March 15, April 28, May 1 (Informal conversation) May 3 May 22	(Both Observation, Informal conversation) March 30, April 10, April 11, April 13, April 17, April 19, May 1, May 5, May 9 (Observation) April 25, March 28 (Informal conversation) May 11