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Examining teacher epistemic orientations toward teaching science (EOTS) and its relationship to instructional practices in science

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EXAMINING TEACHER EPISTEMIC ORIENTATIONS TOWARD TEACHING SCIENCE (EOTS) AND ITS RELATIONSHIP TO INSTRUCTIONAL PRACTICES IN SCIENCE

by

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CERTIFICATE OF APPROVAL

PH.D. THESIS

This is to certify that the Ph.D. thesis of

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has been approved by the Examining Committee for
the thesis requirement for the Doctor of Philosophy degree
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This work is dedicated to my parents and my husband for their unconditional love and endless support. I love you all.

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ABSTRACT

The purpose of this study was to identify essential features of Epistemic Orientation toward Teaching Science (EOTS) and to explore the relationships between EOTS and instructional practices. This study proposes a new concept, EOTS: defined as a teacher's set of interrelated beliefs that are developed and used when teaching science, and are shaped by the Nature of Knowing in General, the Nature of Knowing in Science, the Nature of Learning, and the Nature of Teaching. The essential elements of EOTS were identified through a comprehensive literature review and refined through a multiple-case study.

The participants of the study were three exemplary fifth grade teachers who had been implementing an Argument-based Inquiry (ABI) approach, called Science Writing Heuristic (SWH), for more than three years and were highly devoted to encouraging their students to engage in science practices addressed in Next Generation Science Standard. Data were collected from multiple sources including semi-structured interviews, Video-Stimulated Recall interviews, classroom observations, researchers' field notes, and classroom artifacts. Data was systematically coded, and each belief and practice analyzed in-depth.

The results identified eleven interconnected beliefs held in common by all three teachers. Among the eleven elements, *How to Learn* was the core belief that was most connected to the others and also aligned well with the *Source of Knowing*, *How to Learn*, *Evidence-based Argument*, and *How to Teach*; this idea established a strong structural foundation for the EOTS. In addition, some elements were

explicitly presented when the teachers made instructional decisions, while others were only presented implicitly.

In addition, prominent patterns of instructional practice were evident across the three cases. The teachers did not plan *how* to teach in advance, rather they made instructional decisions based on their epistemic orientations. In particular, they emphasized a conceptual understanding of the big ideas in science by making connections between students' ideas and the big ideas in science. Constant negotiation (construction and critique) was another pattern observed throughout the lessons. In creating effective learning conditions for conceptual understanding and constant negotiation, teachers used language practices and social, group-work as epistemic tools to help students construct and critique knowledge. Moreover, physical resources, such as physical materials and time, were used in a way that encouraged students to engage in science practice. More importantly, the way in which classroom practices and dialogue were managed relied heavily on the essential elements of ETOS. Specifically, *How to Learn* and *Control of Learning* influenced the student-centeredness of their instructional practices.

This study provides several implications for teacher education and research. Teacher-education programs should focus energy on shaping teacher ideas about learning, and address the epistemic foundations of science practices. Further investigation into the essential elements of EOTS, and the relationship between these elements and instructional practices must be pursued with diverse subjects, contexts, and methodologies, to develop a fuller understanding of how these elements work as a whole.

PUBLIC ABSTRACT

This study explored teacher Epistemic Orientation toward Teaching Science (EOTS), which was defined as a teacher's set of interrelated beliefs that they develop and utilize when teaching science. This multiple-case study examines beliefs and practices of three exemplary elementary teachers who were devoted to encouraging student engagement in science practices that are addressed in Next Generation Science Standards (NGSS). Central to this study is the idea that, to improve the teaching of science in the K-12 classroom, teacher education programs must teach more than strategies and skills: a teacher's epistemic orientation should be prioritized or at least considered in teacher education program. A key finding of this work was that teacher beliefs about knowledge and knowing, nature of science, learning, and teaching must be well aligned to each other in order to form strong orientation to teaching science. The study also suggests that teacher educators should challenge teachers' beliefs about learning (how students learn and control of learning), rather than beliefs about teaching, to initiate changes in their orientation to teaching science. The findings of this study provide a guidance to teacher educators by pointing to essential components of beliefs and practices that are compatible with current reform movement in science education (e.g. NGSS).

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CHAPTER ONE

INTRODUCTION

Major reform efforts in science education—including the most recently released Next Generation of Science Standards (NGSS)—encourage teachers to engage students in learning science through science practice. However, science teachers have difficulty with the concept of science practice or inquiry. The Trends in International Mathematics and Science Study (TIMSS) Video Study reported that science lessons in the US typically involved "a variety of activities that may engage students in doing science work, with less focus on connecting these activities to the development of science content ideas" (Roth et al. 2006, p. 21). The TIMSS Video Study concluded that teachers in the U.S. sample did not actively encourage students' conceptual understanding of science. The difficulty might arise from a teacher's set of beliefs that guide their actions and how these actions impact student conceptual understanding (Clark & Peterson, 1986). Therefore, it is important to understand what theoretical orientations need to be developed for teachers to successfully foster student learning through science practice.

Science practice is a social endeavor that encompasses both individual understanding and social norms supported by a science community. In this sense, teaching science through science practice is radically different from the traditional teaching approach. The traditional approach focuses on the transfer of information and rote learning (Tobin & Fraser, 1990); in contrast, teaching through science practice focuses on "learners' epistemologies" (Duschl & Gitomer, 1991, p.847). When examining teaching in a classroom that embraces the premise that learning science is a social endeavor, the focus of classroom practice can be determined by how much teachers are devoted to helping students construct knowledge in social contexts and engage in higher order thinking rather than reproducing knowledge (Elen & Clarebout, 2001).

Teaching science through science practices cannot be prescribed in simple curricular activities. Teachers must shift their orientation away from a teacher-centered approach, which emphasizes recalling factual knowledge, to a student-centered approach which encourages students to actively engage in the construction and critique of knowledge. In this light, it is important for teachers to have beliefs that support these approaches to teaching. These are the beliefs teachers hold about the nature of knowledge and knowing which are referred to as epistemological beliefs (e.g., Hofer & Pintrich, 1997; Schommer, 1990). Windschitl (2002) argued that encouraging teachers to change their epistemological beliefs is a priority and should be the explicit emphasis of teacher development: "without such change as a priority, efforts directed at teacher development become narrowly focused on changing the kinds of attributes and skills that may be added to, subtracted from, or modified" (p. 143).

Several studies showed the impact of epistemological beliefs on curriculum selection and implementation in science. For example, in a study focusing on three 12th grade biology teachers, Benson (1989) found the teachers' view of knowledge were reflected in how they interpreted their curriculum. More importantly, a teacher's epistemological beliefs are closely linked to how a teacher actually teaches in the classroom. The way in which teachers conceptualize the nature and justification of knowledge and their ideas about students' learning influence the features of classroom discourse. Chan and Elliott (2002) revealed that epistemological belief affects both the way a teacher understands the essence of intellectual tasks and the strategies the teacher selects in dealing with complicated and unstructured practices in a class. A teacher's epistemological beliefs can shed light on his or her views about both student knowledge and the processes by which students develop that knowledge as well as how they use curriculum materials.

While there is little debate that epistemological beliefs play an important role in the teaching and learning process, questions remain regarding how teachers' epistemological beliefs should be conceptualized for teaching. Teacher beliefs are difficult to define; this difficulty has led to the messiness of epistemological beliefs in the literature. Theoretical models of epistemological beliefs have used different terms to identify specific beliefs (Hofer & Pintrich, 2004). Although many psychologists, including Hofer and Pintrich (1997), defined epistemological beliefs in its purest form—the nature of knowledge and knowing—there are still controversies over whether the belief regarding learning and teaching should be included in the construct of epistemological beliefs. Many researchers acknowledge the importance of beliefs about learning and other beliefs in educational contexts.

Although I agree that epistemological beliefs should be defined in its purest form, I believe it is theoretically and practically important to create an integrated model that explains how different teacher beliefs in regard to the nature of knowledge and knowing, learning, and teaching are related to teachers' instructional practices. To achieve this goal, this study proposes a new concept, Epistemic Orientation toward Teaching Science (EOTS), defined as a set of interrelated beliefs that a teacher develops and utilizes regarding the dimensions listed: 1) Epistemological Beliefs in General, 2) Epistemological Beliefs in Science, 3) Beliefs about Learning, and 4) Beliefs about Teaching. With this new concept, this study aims to explain the interrelationship between these beliefs, how they shape teaching orientations, and how they are utilized when teachers make instructional decisions.

Another problem researcher often encounters when examining the relationship between teacher beliefs and practice in science is a lack of understanding of the nature of science practice. The recently released framework for K-12 science education outlined eight science practices and encouraged science teachers to engage students in the learning process through science practice. The framework purposefully uses the term “science practice” rather than “science processes” or “inquiry” skills to explain and extend the meaning of "inquiry in science and the range of cognitive, social and physical practices that it requires" (NRC, 2012, p.19). Nevertheless, this guideline did not provide a clear picture of how the set of practices should be implemented by teachers in a K-12 classroom. As a consequence, both the framework and the literature in science education offer little in the way of an empirically grounded framework or even resources that prepare teachers to help students learn science through science practice (Windschitl et al., 2012).

To understand what science practice should look like in a real-world classroom, one should understand that science practice encompasses “cognitive, social and physical practices" (NRC, 2012, p.19). The cognitive aspect of science not only refers to knowledge or outcomes produced by science practices, it also refers to the process itself or the epistemology reflected in it. Indeed, many scholars have argued that epistemology ought to be a central component of science education (e.g., AAAS, 1993; Duschl, 2000; NRC, 2000), positing that students must understand the processes by which scientific ideas are advanced and justified, as well as scientific knowledge. In this sense, we should take both science content and epistemology of science into consideration. However, one should note that science epistemology should be incorporated into the concepts rather than separated from them. Therefore, the epistemological aspect should be considered a facet of cognitive practice.

While cognitive practice that embraces both knowledge and epistemology of science is a key facet of science practice, it is also critical to appreciate that scientific practice is social in nature. Science as social practice describes how a community continually construe what counts as knowledge. This social aspect of science is reflected in how meaning of scientific ideas are negotiated in science class. In this practice of science, language plays a critical role (Gee, 2004; Hand, 2008; Norris & Phillips, 2003). Scientists communicate through different forms of language including written text, multimodal representations, and speech, which together comprise the medium in which the scientific community develops ideas. This central role of language in scientific practice has received a growing attention from science educators. In this regard, understanding how language works to construct social learning environments in the science classroom is essential for teachers to appreciate as they encourage students to develop scientific knowledge through the practice of science.

Whereas designing a classroom environment that encourages student engagement in cognitive and social aspects of scientific practice is a key factor, this requires sustained and dense practice. Hence, teachers must manage time and resources appropriately, providing opportunities for students to engage in scientific practice. This is fundamentally related to teachers' instruction for providing students with sufficient time to deal with ideas in depth (Collins, 1998) or providing sufficient access to sources of information in the classroom. Taking these ideas into consideration, this study examines how a teacher take cognitive, social, and physical resources into consideration when they create learning environments; thus, I outline tangible features of classroom practices that are embodied by a learning environment designed for science practice. Science practice will be viewed from a holistic standpoint, one that reflects three dimensions: 1) a cognitive dimension, 2) a social dimension, and 3) a physical dimension.

Purpose of the Study

The purpose of this study is 1) to identify the core elements of a teacher's Epistemic Orientation toward Teaching Science (EOTS) that are related to instructional practices aligned with theoretical bases of science practice, and 2) to understand the relationship between these core elements of the EOTS and a teacher's instructional practice, at the cognitive, social, and physical levels.

First, this study aims to conceptualize EOTS by closely examining three experienced elementary teachers and comparing how their thoughts and beliefs influence their instructional practices. EOTS is operationally defined in this study as a teacher's set of interrelated beliefs that is developed and utilized when conceptualizing teaching science. EOTS shapes a teacher's instructional practices, involving planning, enacting plans and interacting with students, all of which determine how well the teacher engages students in science practice. This idea rests on a foundation of personal epistemology theories developed by educational psychologists (e.g. Hofer & Pintrich, 1997). Yet, whether beliefs about learning and teaching should be included in epistemological beliefs framework remains controversial. In order to capture all epistemological issues related to teaching science, this study aims to re-conceptualize the idea by offering the alternative concept of EOTS, which encompasses both the core area of epistemological beliefs and beliefs about learning and teaching. Building on research into teacher beliefs, this study empirically explores the beliefs of three exemplary teacher subjects, to characterize the core elements of their EOTS and its relationships to teaching. Using this novel approach, this study seeks to improve the understanding of how, in the real world, teachers' beliefs shape ways of viewing teaching science and how those views are reflected in teaching practices that foster students' engagement of science practice.

Second, this study aims to examine the relationship between EOTS and instructional practices. It will focus on how a teacher's set of beliefs guides his/her use of resources to shape their instructional practices. Instructional practice refers to routine activities teachers engage in that are devoted to enactment of plans and dialogical interaction intended to support student learning (Windschitl et al. 2012). To examine how teachers' instructional practice(s) create an engaging learning experience, the framework developed by Ford and Forman (2006) and Kuhn et al. (2013) introduces three dimensions of instructional practice: the cognitive (epistemological) dimension, the social dimension and the physical dimension. The framework was chosen because of its alignment with the theoretical foundation of science practice addressed in NGSS. At the foundation of the study described here is a conceptual model that describes the relationships between a set of the essential beliefs and the selection of teaching practices involving enactment and dialogical interaction. Figure 1 provides a schematic of the conceptual framework for this study. This will provide insight into the ways teachers shape their instructional practices and how those practices create classroom discourse for fostering student engagement of science practice.

Research Questions of the Study

To identify the core elements of EOTS and understand the relationship between teachers' EOTS and their instructional practices, and how this relationship influences student engagement in science practice, this study poses the following questions:

1. What are the core elements of a teacher's EOTS that are related to instructional practice fostering student engagement in science practice?

2. How are the core elements of teachers' EOTS related to a teacher's use of the three resources of instructional practices: the cognitive, social, and physical dimensions?

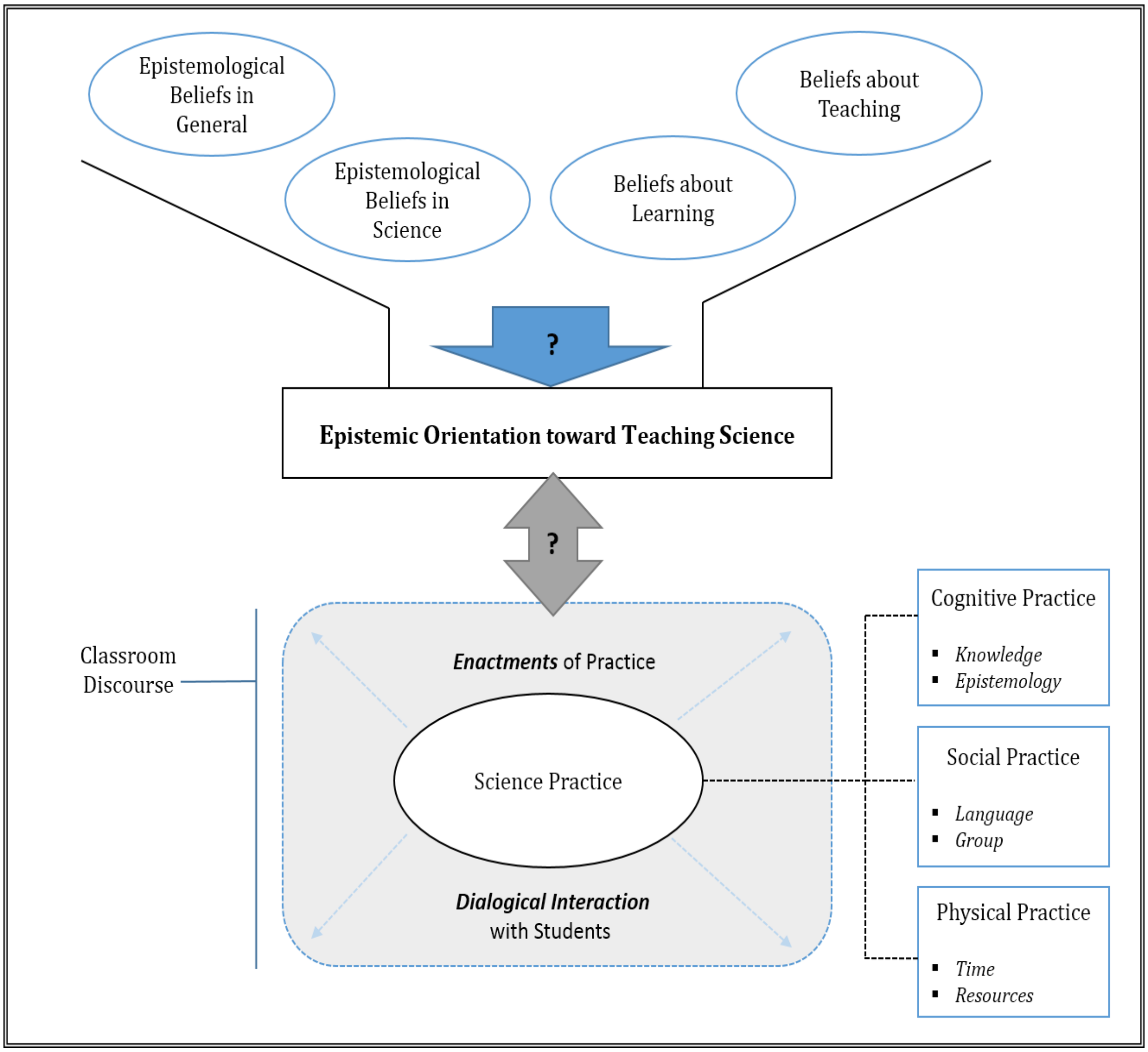

Figure 1. Conceptual Framework for the Study

Significance of the Study

Major reform efforts in science education—including the most recently released NGSS that encourage teachers to shift from traditional information transfer to practices oriented toward creating student-centered learning environments—have focused on the attention of psychologists and educators on teacher epistemology (e.g., Hofer & Pintrich, 1997; Windshitl, 2002). "Epistemology," as defined in this study and as commonly used in the educational research literature, is a set of theories and beliefs about knowledge. These theories address a wide range of important human experiences, such as how we come to know what we know, or why we prefer certain ideas over others. Understanding a teacher's epistemological beliefs helps us to see how the teacher views both student knowledge and the processes by which students acquire and develop that knowledge. A teacher's epistemological beliefs are closely linked to how a teacher actually teaches in the classroom. Specifically, the discussion has focused on the significant relationship between a teacher's epistemological beliefs and their tendency to adopt specific pedagogical practices, since these beliefs shape how teachers view students' understanding and how students develop knowledge through practice (Chan, 2003; Luft & Roehrig, 2007). Clearly, epistemological beliefs are the crucial criteria that influence teachers' perception of teaching and learning. In this regard, this study explores how teachers' sets of beliefs about knowledge, learning, and teaching provide resources for teachers to address the many facets of instructional practices that are embodied in learning environment. This will provide insights into the ways teachers determine their instructional practices to foster student learning through scientific practice.

Most of the epistemological belief theories focus on two primary areas: the nature of knowledge and the nature of knowing; however, it is controversial whether beliefs about learning and teaching should also be included. This controversy persists due to a lack of understanding about the relationship between epistemological beliefs and beliefs about teaching and learning. Moreover, the dimensions or constructs used to investigate these beliefs have been defined and applied inconsistently. To clarify these issues, this study proposes the concept of EOTS, a novel concept that will aid our understanding of how teachers' sets of thoughts and beliefs are reflected in their enactments of practice and dialogical interaction dealing with student learning. The work described here explores the beliefs and thoughts shared by three expert teachers who successfully implement an Argument-Based Inquiry that reflects the essential norms of scientific practice. The study seeks to identify the essential elements of EOTS that can be targeted in endeavors aimed at improving the teaching of science in the K-12 classroom. This understanding can provide useful implications for teacher education by suggesting best approaches for developing quality science teachers.

In guiding science teachers in the classroom, NGSS advocate teaching in a way that engages students in scientific practice so that they grasp the epistemology of science (NRC, 2012). In other words, scientific practice should address epistemic goals that focus on "how we know what we know, and why we believe the beliefs of science to be superior or more fruitful than competing viewpoints" (Duschl &

Osborne, 2002). Chinn and Malhotra (2002) argue that epistemologically authentic scientific reasoning is important because all people are faced with issues that require them to reason about complex issues involving evidence (e.g., health issues). More importantly, addressing epistemology in elementary science education should be emphasized because the ideas about scientific knowledge that students develop in the early grades likely influence how they engage with science later in life. Although the new framework articulates eight practices of science emphasizing epistemology of science, they do not provide a clear picture of how to create learning environments for these practices. In this regard it seems necessary to examine elementary teachers' instructional supports that are embodied in the student-centered learning environments they create. By thoroughly examining multiple dimensions of scientific practices that involve the cognitive, social and physical dimensions of three expert teachers, this study could illustrate how teachers should support student learning about epistemology of science through scientific practices in a classroom.

Summary

In this chapter, the purpose, the research questions, the rationale, and the theoretical framework of this study were discussed. The next chapter discusses the relationship between teacher epistemology and teaching, conceptualization of the EOTS, multi-facets of science practice, and argumentation as epistemic practice through comprehensive review of literature.

CHAPTER TWO

LITERATURE REVIEW

This chapter contains the conceptual, theoretical, and empirical research that is relevant to the study, and includes information related to the following areas: 1) Teacher Beliefs and Practice; 2) Personal Epistemology and Teaching; 3) Conceptualization of EOTS; 4) Creating Learning Environment for Science Practice; and 5) Argumentation in Science Practice

Teacher Beliefs and Practice

Belief is an emotional tendency that constitutes a person's understanding and guides their decisions. Belief, in turn, drives a person to realize their decisions. Richardson (1996) defined beliefs as a "psychologically held understandings, premises, or propositions about the world that are felt to be true" (p. 103). Teachers' beliefs affect their decision-making process, educational orientation and goals, and every process in their teaching. In other words, beliefs act as filters through which teachers make decisions about instruction and play a crucial role in what teachers do in their classrooms (Richardson 1996). Pajares (1992) claimed that even though teachers' knowledge affects their decision-making process, their behaviors in class are the consequences of their beliefs that have been built up with various experiences. Many studies have indicated that these beliefs significantly influence teachers' behaviors in class and the educational environment they create (e.g., Kagan 1992; Nespor, 1987). Teachers' beliefs are therefore relevant to understanding what they do when attempting to enact reform because they "can guide instructional decisions, influence classroom management, and serve as a lens of understanding for classroom events" (Luft and Roehrig 2007, p. 38).

In science education, research on reformed-based beliefs has been linked to classroom use of inquiry and other constructivist practices (e.g., Hashweh, 1996; Yerrick et al. 1997). What teachers believe about inquiry and their knowledge base for implementing inquiry influences their inquiry practice (Keys & Bryan, 2001). Teachers who hold personal beliefs about the value of inquiry promote scientific inquiry in their classrooms (Keys & Bryan, 2001; Wallace &Kang, 2004). Pajares (1992) found that a strong literature base suggests "a strong relationship between teachers' educational beliefs and their planning, instructional decisions, and classroom practice" (p. 326).

Despite the importance of the impact of beliefs on practice, beliefs are tacit and sometimes even unconscious. Moreover, beliefs appear to be relatively stable and resistant to change (Kagan 1992). Specifically, Beliefs that are more central and more interconnected are more resistant to change (Luft, Roehrig, & Patterson, 2003). In addition, prior studies have identified inconsistencies between what teachers believe and what they actually do in classrooms (Fang 1996). For example, King et al. (2001) found disconnect in elementary school teachers' descriptions of their work as hands-on and inquiry-oriented and the researchers' observations of lessons they characterized as didactic. Richardson (1996) argued that beliefs are better understood as being interactive with teachers' practices, rather than dictating them. In this regard, the present study focuses on *how* teachers' beliefs are interactively related to their practice, rather than focus on whether their practices are aligned with their beliefs or not.

Personal Epistemology and Teaching

Epistemology refers to a set of theories and beliefs about knowledge. Personal epistemology is concerned with the origin, nature, limits, methods, and justification of human knowledge and addresses a wide range of important human experiences, such as how we come to know what we know, or why we prefer certain ideas over others. When we encounter new information, we are influenced by the beliefs we hold about knowledge and knowing. Hofer (2002) offers the following examples to illustrate how personal epistemology influences learning and knowing: "As we read the morning paper, we make judgments about the credibility of the claims in the particular article. In our professional lives, we confront the learning of a new skill and make determinations about their particular value" (Hofer, 2002, p. 3). Research geared towards personal epistemology is an important area that many educational researchers and psychologists continue to pursue (Hofer, 2001; Hofer & Pintrich, 1997).

Numerous studies on personal epistemology have used different paradigms and labels, including epistemological theories, epistemological worldviews, epistemological development, epistemic cognition, epistemological beliefs, epistemological reflection, and epistemological resources; and the list goes on. Pintrich (2002) categorized these various approach into three general ways of researching personal epistemology: 1) developmental (e.g., epistemological development), 2) cognitive (e.g., epistemological beliefs), and contextual (e.g., epistemological resources). In the context of teaching, this study uses personal epistemology to refer to beliefs about knowledge and knowing, which are epistemological beliefs.

Epistemological beliefs focus on the manner in which individuals come to know, their beliefs about knowing, and how those beliefs are a part of and influence cognitive processes (Hofer & Pintrich, 1997). These beliefs are activated as learners engage in learning and knowing. In a more formal context, epistemological beliefs have significant influence upon students' learning process and educational achievements (Schommer, 1990, 1993; Brownlee, Purdie, & Boulton-Lewis, 2003). Research has suggested epistemological beliefs influence reasoning, interpretation of knowledge, and monitoring of cognition (Hofer & Pintrich, 1997; Pajares, 1992). In addition, epistemological beliefs of students are thought to be related to numerous variables such as cultural background (Chan & Elliott, 2000), conceptual change (Mason, 2003), critical thinking (King & Kitchener, 1994, 2002), and motivation (Hofer, 1994). While a number of studies have shown that students' epistemological beliefs influence their learning processes, little is known about how teacher's epistemological beliefs influence how they approach teaching (Brownlee et al., 2001; Kang, 2008).

As one sort of belief, a teacher's epistemological beliefs are closely linked to how a teacher actually teaches in the classroom. The way in which teachers conceptualize the nature and justification of knowledge and their ideas about students' learning influence the features of classroom discourse. Chan and Elliott (2002) reveal that epistemological belief is an important factor affecting both the way a teacher understands the essence of intellectual tasks and the strategy the teacher selects in dealing with complicated and ill-structured tasks in a class. Under a student-centered classroom discourse, teaching takes place in ill-structured situations not in structured situations based on a planned process. In this regard, it can be deducted that epistemological beliefs are placed on important positions in student-centered teaching. In line with this finding, more researchers have become interested in teacher epistemological beliefs (Hofer & Pintrich, 2002; King & Kitchener 2004).

Several studies have investigated preservice teachers' epistemological beliefs and their conception of teaching. Research suggested that understanding preservice teachers' beliefs is extremely important to improving their professional learning and teaching practices because they bring their own beliefs to the teacher-education programs (Pajares, 1992). In particular, preservice teachers' epistemological beliefs are related to their approach to learning (Brownlee & Berthelsen, 2006; Chan, 2003), teaching goal (Kang, 2008), teaching conceptions (Yadav & Koehler, 2007), and their teaching practices (Tsai, 2003). Brownlee (2004) found that preservice teachers who held relativist beliefs tended to view teaching as facilitating the learning process, whereas those holding objectivist epistemology viewed teaching as transmission of knowledge. Similarly, Hashweh (1996) also found that teachers with constructivist epistemology tended to use more effective teaching strategies, such as teaching for conceptual change.

Teacher epistemological beliefs have also received growing attention by researchers in science education. Reform efforts in science education have encouraged teachers to create learning environments where students can actively make sense of nature for themselves (AAAS, 1993; NRC, 2000, 2007, 2013). As discussed previously, in a student-centered classroom, the direction of the lesson and discourse is mostly determined by students' ideas rather than by a teacher's plans or guides. In this case, it is necessary for science teachers to shift their focus of instruction from designing well-organized lessons to creating an environment where students actively participate. Given the fact that constructing the learning environment for students' engagement in science practice makes instructional approach epistemologically different from the traditional teaching approach that has focused on transmission of knowledge, creating such learning environments is neither common nor easy. Windschitl (2002) argues that encouraging teachers to change their epistemological beliefs is a priority and should be the emphasis of teacher development. In such contexts, teacher epistemological beliefs have received new attention in science teacher education.

Conceptualization of Epistemic Orientation toward Teaching Science

While little debate has focused on the importance of epistemological beliefs in teaching and learning, questions remain as to how epistemological beliefs should be conceptualized in an educational context. To develop better conceptualization, there are three theoretical issues that should be taken into consideration. Epistemological beliefs as 1) a unidimensional versus multidimensional construct;

2) a purest form versus integrated form; and 3) domain-general versus domain-specific.

Unidimensional versus Multidimensional

The study of epistemological beliefs has been divided into two major lines of research. The first line focuses on identifying developmental stages and conceive epistemological beliefs as a unidimensional construct. Unidimensional models were suggested by early scholars like Perry (1968). Perry (1968) claimed that the way of interpreting educational experience can be explained in terms of several sequential positions about the nature of knowledge and knowing and his characterization of epistemological development was supported by other models (Baxter Magolda, 1992; Kuhn, 1991). However, the developmental stage model has brought its many critiques due to a lack of consistency in terms of the elements of epistemological beliefs and each stage of development. On the other hand, the second line of research views epistemological beliefs as a system of independent beliefs. Shommer (1990, 1994) claimed that epistemological beliefs should be seen as multidimensional construct that comprise of five dimensions: source of knowledge, certainty of knowledge, structure of knowledge, speed of learning, and ability to learn. She claimed that a comprehensive consideration of the multidimensional aspects of epistemological beliefs is necessary to properly explain learning and teaching behaviors related to these beliefs (Schommer, 1990, 2004). In addition, an individual's epistemological belief and its development are too complicated to be captured in a single dimension. It is also believed that the various epistemological beliefs can develop and have an effect separately. In this sense, epistemological beliefs is regarded as a multidimensional construct in this study to establish a better conceptual model that explains the relationship between teacher epistemological beliefs, other beliefs related to learning and teaching, and their instructional practices.

A Purest Form versus Mixed Form

There is a lack of agreed-upon definition or model of epistemological beliefs, and research has been labeled under different constructs. Namely, different researchers use different terms to identify a specific belief, although these constructs overlap considerably (Hofer & Pintrich, 2004; Maggioni & Parkinson, 2008). Thus, the results of research have appeared in disparate locations. Recently researchers have begun to agree on a definition of epistemological beliefs in their purest form—beliefs about nature of knowledge and knowing. However, controversies persist over whether beliefs regarding learning should be included in the set of key epistemological beliefs. Although many researchers argue that epistemological beliefs should be defined in the purest form, they acknowledge the importance of beliefs about learning and other beliefs in educational contexts. In particular, several studies demonstrated that epistemological beliefs are closely related to beliefs about learning and teaching (Chan, 2004). Hofer and Pintrich (1997) also supported this notion by arguing that "beliefs about learning and teaching are related to how knowledge is acquired, and in terms of the psychological reality of the network of individuals' beliefs, beliefs about learning, teaching and knowledge are probably intertwined" (p.116). In addition, epistemological beliefs are also considered "the philosophical basis for teaching and learning" (Kukari, 2004, p.107). However, we still lack evidence in the area of epistemological beliefs and beliefs about learning and teaching. Although some research (e.g. Hofer and Pintrich, 1997) chose to define epistemological beliefs in their purest form, beliefs about learning and other beliefs related to learning and teaching need to encompass the big picture (Shommer, 2002). By investigating these beliefs together within a conceptual framework, we will enhance our understanding of how these beliefs are related to each other and operate together to shape instructional practices.

Domain-General versus Domain-Specific

Another concern among researchers is whether epistemological beliefs should be regarded as domain-general or domain specific beliefs. Whereas most of early work on personal epistemology focused on domain-general beliefs about knowledge and knowing (e.g. Perry, 1970; Schommer, 1990, 1994), recently researchers have paid attention to domain-specific beliefs (e.g. Hofer, 2000; Samarapungavan, Westby & Bodner, 2006). Researchers suggest epistemological beliefs of disciplinary knowledge may be distinct from beliefs about general knowledge. Hofer (2001) and Tabak & Weinstock (2005) argued that domain-general and domain-specific beliefs should be considered together to improve our understanding of epistemological beliefs in teaching and learning. However, few have attempted to examine domain-general and domain-specific epistemological beliefs together. Hence, the theoretical framework of this study includes both domain-general and domain-specific (science) epistemological beliefs to examine how they operate together in shaping instructional practices.

As a way to grapple with all these issues constructively, this study proposes a new concept, Epistemic Orientation toward Teaching Science (EOTS), defined as a set of interrelated beliefs that a teacher develops and uses when teaching science. This set of beliefs includes beliefs about 1) knowledge and knowing in general, 2) knowledge and knowing in science, 3) learning, and 4) teaching. When conceptualizing the EOTS, this study assumes that the EOTS is a multi-dimensional construct that consists of semi-independent and interrelated beliefs. In addition, this study intentionally uses "orientation", rather than "beliefs" or "cognition" to conceptualize this new idea in a way that allows us to understand how the set of beliefs determines and predicts the direction of teaching in the classroom. Indeed, this study aims to identify, both theoretically and practically, essential beliefs that a teacher uses when teaching science.

The theoretical sub-dimensions of each of four belief dimensions were conceived during a literature review of teacher epistemological beliefs and beliefs about learning and teaching. First, seven theoretical models of personal epistemology were reviewed to identify major dimensions of domain-general epistemological beliefs and beliefs about learning. Table 1 shows the dimensions that were included in the theoretical models of personal epistemology. Although some of these models (e.g. Perry, 1968) regarded personal epistemology as a unidimensional construct, all distinguishable aspects were identified through the analysis.

Table 1. Analysis of Seven Theoretical Models of Personal Epistemology

Scholars	Model	Nature of Knowledge		Nature of Knowing		Nature of Learning and Teaching		
		Certainty of K	*Structure of K*	*Source of K*	*Justification for Knowing*	*Speed of Learning*	*Ability to learn*	*Learning Process*
Perry(1968)	*Intellectual and ethical development*	X		X				
King & Kitchener(1981)	*Reflective Judgement*	X	X	X	X			X
Belenky et al. (1986)	*Women's way of knowing*			X				
Baxter Magolda (1992)	*Epistemological Reflection*	X		X	X		X	
Schommer(1991)	*5-Dimensional Model*	X	X	X		X	X	
Jehug, Johnson & Anderson (1993)	*Modified 5-dimensional Model*	X	X				X	X
Chan & Elliott(2002)	*2*2 dimensional model*	X		X			X	X

As shown in Table 1, six dimensions have been included in at least two major models of epistemological beliefs; Speed of Learning was only included in Schommer's model (1991). These six dimensions were refined and confirmed through further literature review of empirical studies on teacher epistemological beliefs. Due to a lack of theoretical models of epistemological beliefs in science and beliefs about teaching, a literature review of empirical studies was used to identify the sub-dimensions of these two dimensions. The final sub-dimensions of four beliefs dimensions are discussed in the following sections.

Teacher Beliefs about Knowledge and Knowing in Science

Through review of the major theoretical models of epistemological beliefs, this study identified four sub-dimensions of domain-general epistemological beliefs: 1) Changeability of Knowledge, 2) Structure of Knowledge, 3) Source of Knowing, and 4) Justification of Knowing. Although several other dimensions have also received attention, these four dimensions are considered the core dimensions of epistemological belief (Hofer and Pintrich, 2002). The first two dimensions concern the nature of knowledge and the third and fourth dimensions are related to the nature of knowing that describes the process of knowing. Changeability of Knowledge concerns whether knowledge is certain or uncertain and whether it is changeable or fixed. This belief is often conceptualized along a continuum of knowledge ranging from unchanging to constantly evolving. Feucht and Bendixen (2010) found that most preservice elementary teachers viewed knowledge as uncertain and always changing. Structure of Knowledge deals with whether knowledge is simple or complex, and whether it is inseparable or fragmentary.

Bendixen and Corkill (2011) found teachers tended to view knowledge as complex (rather than simple and factual) if they had more years of teaching. They asserted that a belief that knowledge is simple and certain could be related to teachers' beliefs that instructional practices should be very simple and straightforward.

On the other hand, beliefs about the Source of Knowing concerns whether a person believes knowledge comes from authorities or individuals, and where knowledge resides; internally and/or externally. Justification of Knowing shows the procedures to evaluate and warrant knowledge claims. Chan (2003) found that teachers' beliefs that knowledge is transferred by an external authority were negatively correlated with deep learning approach.

Teacher beliefs about Knowledge and Knowing in Science

There are two lines of research in regard to teacher epistemological beliefs in science. The first line has been devoted to exploring epistemological beliefs about science and scientific knowledge (e.g., Lederman, 1992; Akerson et al., 2000). In the last two decades, researchers in science education have engaged in much research about the views of the nature of science (NOS), and its impact on teaching strategies (e.g. Lederman & Lederman, 2004; Duschl, 1990; Hanuscin & Akerson, 2006; Osborne et al., 2003). The NOS involves the values and beliefs important for the development of scientific knowledge (Lederman, 1992). In addition, this line of research assumed that NOS is a knowledge that provides ways of thinking and criticizing about other knowledge types. While there is no universal definition or conceptualization of NOS, various approaches have been undertaken to examine the relationship between teacher view of NOS and their practices. Gallagher's (1991) ethnographic research study examined 27 secondary science teachers, which focused on their understanding of the NOS and how this influenced their teaching. In this study, most teachers held reform-based views of their purpose for teaching science; yet, their instructional methods were characterized as traditional approaches. In contrast to Gallagher's study, Brickhouse (1989) found that three secondary teachers' views of the NOS were consistent with the instructional strategies they used to teach their subject. Mellado, Bermejo, Blanco, and Ruiz (2007) also found that secondary biology teachers held beliefs about the NOS and teaching and learning science that differed from their practice. On the other hand, the second line of research examines teachers' scientific epistemological beliefs by considering similar constructs that were used in research on domain-general epistemological beliefs (Liu & Tsai, 2008). Five features of scientific knowledge and development suggested by Tsai and Liu (2005) included the tentative feature of scientific knowledge (changeability of knowledge): the role of social negotiation in the science community (Justification of knowing), the creative nature of science (source of knowledge), the theory-laden quality of scientific exploration (source of knowledge), and cultural impact on science. While both lines of research used different paradigm and labels, there seems to be many overlapping features in terms of knowledge and knowledge development.

Epistemology of science or epistemological beliefs about science also have been emphasized in science standards for the past few decades (e.g. AAAS, 1993; NRC, 1996, 2012). Recently released science standards, NGSS, also included eight features of scientific knowledge and development, encouraging teachers to incorporate these into science practices and cross-cutting concepts in the classroom. These are:

- Scientific Investigations Use a Variety of Methods
- Scientific Knowledge is Based on Empirical Evidence
- Scientific Knowledge is Open to Revision in Light of New Evidence
- Scientific Models, Laws, Mechanisms, and Theories Explain Natural Phenomena
- Science is a Way of Knowing
- Scientific Knowledge Assumes an Order and Consistency in Natural Systems
- Science is a Human Endeavor
- Science Addresses Questions About the Natural and Material World

According to the guideline of NGSS, the first four features are related to practices and the second four to crosscutting concepts. Since this study aims to identify essential beliefs that are compatible with theoretical foundations of the current reform movement in science education (e.g., NGSS), all eight features are regarded as theoretical sub-dimensions of science-specific epistemological beliefs. However, to make these dimensions more comparable to domain-general epistemological beliefs, these features were categorized into three dimensions of epistemological beliefs as seen in Table 2.

Table 2. Dimensions of Epistemological Beliefs in Science

Dimensions of Epistemological Beliefs	NOS in NGSS
Changeability of Knowledge	• Scientific Knowledge is Open to Revision in Light of New Evidence
Process of Knowing (Source of Knowing)	• Scientific Investigations Use a Variety of Methods • Scientific Models, Laws, Mechanisms, and Theories Explain Natural Phenomena • Science is a Human Endeavor • Scientific Knowledge Assumes an Order and Consistency in Natural Systems
Justification of Knowing	• Science is a Way of Knowing • Scientific Knowledge is Based on Empirical Evidence • Science Addresses Questions about the Natural and Material World.

In short, this study includes the eight dimensions of scientific epistemological beliefs that are related to three dimensions of domain-general epistemological beliefs. Teachers' beliefs about how science is developed may be potentially related to not only their domain-general epistemological beliefs but also their beliefs about how to teach science and how students learn science.

Beliefs about Learning

As mentioned above, this study identified two major dimensions of learning which have been included in the major model of epistemological beliefs. These two dimensions are 1) Ability to Learn, and 2) How to Learn (the learning process). Several studies demonstrated that beginning teachers tended to view intelligence and ability as fixed and innate (e.g., Dweck & Bempechat, 1983; Patrick & Pintrich, 2002). On the contrary, Bendixen and Corkill (2011) found that the experienced teacher viewed learning ability as more fixed and innate than the preservice teachers, suggesting that more classroom experience made teachers view learning ability as fixed. On the other hand, Jordan and Stanovich (2003) reported that differences in teacher beliefs about the students' abilities are related to difference in their instructional practices. In addition, Schwartz and Jordan (2011) also supported that differences in beliefs about knowledge and the nature of ability appeared to predict how much attention teachers pay to students who had difficulties. It seems to be evident that a teacher's view on student ability affects how they view student learning.

A teacher's beliefs about how to learn were also considered to be important beliefs closely related to epistemological beliefs and affecting instructional practices. Also, this set of beliefs has been shown to be a significant factor in teacher changes in practice (Abd-El-Khalick et al., 1998; Brighton, 2003). In this regard, understanding teachers' beliefs about how students learn is important in painting a complete picture of why teachers resist change.

Beliefs about Teaching

Previous literature established links between teacher' epistemological beliefs and their conceptions about teaching (e.g., Chan, 2004; Tsai, 2002; Qian & Alvermann, 1995). Numerous researchers used the distinction between 'traditional/transmission' and 'constructivist' when they examined the conceptions of teaching (e.g., Chan, 2004; Cheng et al, 2009; Clements & Battista, 1990). These concepts have been seen as either end of a continuum (traditional/transmission versus constructivist), and were used as useful analytic tools. When they conceptualize these teaching approaches, researchers often address three major aspects of teaching: 1) the Role of the Teacher, 2) How to Teach, and 3) the Goal for Teaching. Table 3 shows how these three aspects of teaching are associated with the conceptions of teaching.

Table 3. Conceptions of Teaching

	Constructivist Teaching	**Traditional Teaching**
How to teach	Student-centered Creating learning environments where students are engaged in knowledge construction and critique Emphasizing students' motivation and interaction	Teacher-centered Transmitting core facts and concepts to students Emphasizing textbooks and curriculum materials
Role of teacher	Facilitator, Resources person	Knowledge deliver, Knowledge controller
Goal for Teaching	Helping students develop conceptual understanding and higher-order thinking/evaluation skills	Helping students master first-order domain knowledge and basic procedure

The traditional concept of teaching is often referred to using teacher-centered teaching strategies because knowledge acquisition is affected through a one-way transmission process from the teacher to students. In this context, the teacher plays the major role in knowledge-transmission support; and curriculum materials and textbook content are emphasized. In addition, their goals are related to mastery of first-order domain knowledge and procedures. On the other hand, constructivist teaching is often associated with student-centered teaching which focuses on students' self-motivation and an interactive learning process in which the role of the teacher is that of facilitator (Biggs, 1999; Entwistle et al., 2000; Kember, 1997). Moreover, enhancing higher-order thinking and evaluation skills are the goals for teaching. In this sense, this study includes How to Teach, Role of Teacher, and Goal for Teaching as sub-dimensions of beliefs about teaching.

Taken together, the conceptual framework of EOTS was established. (See Figure 2). Through the literature review, a total of seventeen sub-dimensions were identified. Among these seventeen theoretical dimensions, the essential elements closely related to instructional practices that foster student engagements in science practice will be selected. This study utilizes qualitative research approach; hence, the name and the nature of theoretical dimensions of EOTS could change over the course of the study. Furthermore, this conceptual framework will be refined throughout.

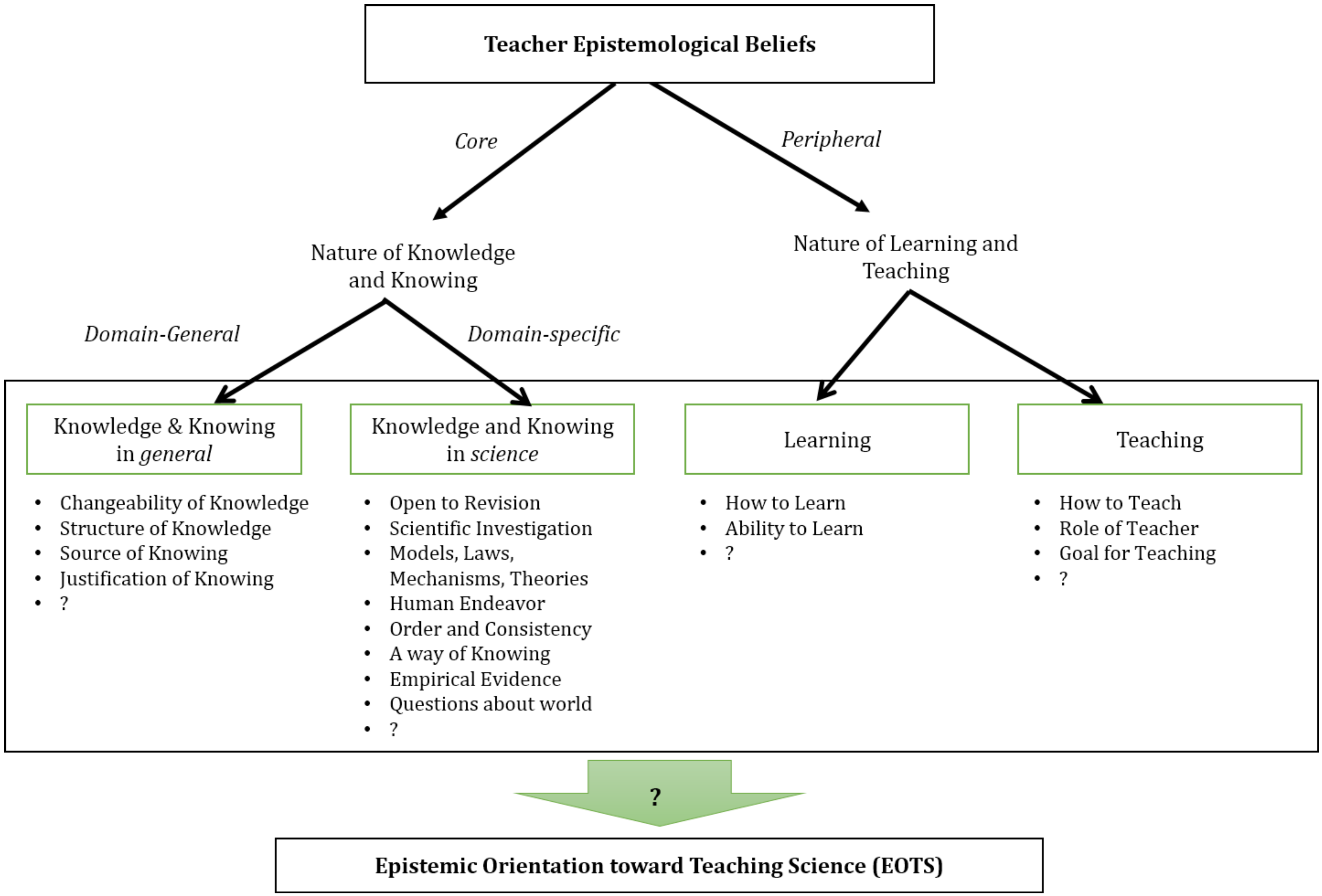

Figure 2. Conceptual Framework of Epistemic Orientation toward Teaching Science

Creating a Learning Environment for Science Practice

According to the Next Generation Science Standards (NGSS; NGSS Lead States, 2013), it is essential for students to be engaged in scientific practice to fully comprehend the nature of scientific knowledge. In other words, students themselves should develop their understanding of scientific knowledge by participating in scientific practice, just as scientists generate scientific knowledge by becoming aware of problems, collecting data, conducting experiments, developing models, and engaging in discussion, etc. In this connection, a number of researchers have tried to find out what science practice on the part of scientists means, aiming at transferring such scientific process and methods into the science classrooms. As a result, they worked out a diverse set of inquiry models or frameworks, highlighting the importance of students developing their scientific understanding through inquiry or science practice.

The new standards purposefully use the term 'Science Practice' rather than inquiry 'skills' or 'methods' to expand the meaning of "inquiry in science by stating that:

> Because the term "inquiry," extensively referred to in previous standards documents, has been interpreted over time in many different ways throughout the science education community, part of our intent in articulating the practices in Dimension 1 is to better specify what is meant by inquiry in science and the range of cognitive, social, and physical practices that it requires. As in all inquiry-based approaches to science teaching, our expectation is that students will themselves engage in the practices and not merely learn about them secondhand. Students cannot comprehend scientific practices, nor fully appreciate the nature of scientific knowledge itself, without directly experiencing those practices for themselves. (p. 19).

In this new framework, eight scientific practices were outlined that explicitly encouraged science teachers to engage students in learning process through the practice of science. Nevertheless, this guideline did not provide a clear picture of *how* the set of practices should be implemented by teachers in a K-12 classroom. Although numerous models offer various facets of science practice, most concerning the inquiry approach reflect on the philosophical stance of the constructivist theory of learning. In the constructivist theory, students construct their own understanding of the natural world through their inquiry activities and reflections on those experiences. Students evaluate and negotiate new information based on their prior knowledge, beliefs, experiences, and evidence. At the same time, teachers encourage the learning experiences of students by creating learning environments that support student investigations and explorations, and by challenging them to go beyond their current level of understanding (Vygotsky, 1987). Fundamentally, science practice requires teachers to move away from a teacher-centered, lecture-based approach, to one that is student-centered, where conceptual understanding is generated and negotiated by students. Nevertheless, both the new framework and the literature provide little in the way of helping adopt a reform-based approach. No concrete framework of instruction is offered for helping students to learn science through scientific practice. In this sense, it is important to understand the many facets of scientific practice and how those different facets are reflected in the classroom environment created by teachers (Windschitl et al., 2012).

To examine how teachers' instructional practices create the learning environment for student engagement in science practice, this study uses three dimensions of instructional practices that were addressed in NGSS. These dimensions are: 1) cognitive, 2) social, and 3) physical (NGSS Lead States, 2013). Since there is no guideline describing how teachers can incorporate these three dimensions into their instruction, this study established a conceptual framework of science practice by modifying the framework of Ford and Forman (2006)' and Kuhn et al. (2013). Ford and Forman (2006) conceptualized disciplinary learning in science around three points from the science-student literature. They noted that scientific practice has social and material aspects and these can be represented by two roles: constructor of claims and critique of claims (Ford & Forman, 2006). On the other hand, Kuhn and others (2013) addressed metacognitive, epistemological, and social dimensions, to develop norms of argumentation. By taking these together, this study views scientific practices as those that reflect the three dimensions: the cognitive (conceptual and *epistemological)* dimension*,* the *social (language and group)* dimension*,* and the *physical (physical material and time)* dimension (See Figure 3). In this conceptual framework, social and physical dimensions are used as tools to create conceptual and epistemological nature of science practice.

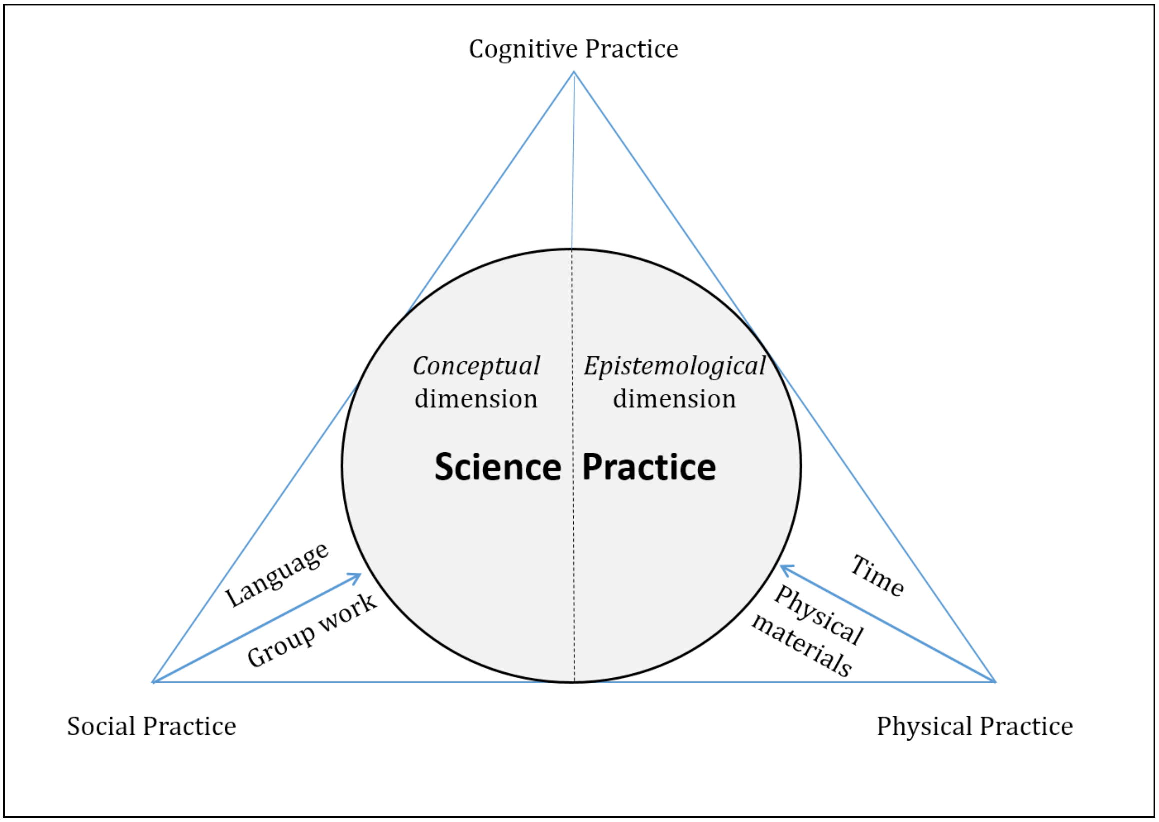

Figure 3. Three Dimensions of Science Practice

Cognitive Dimension

Science practice, as a cognitive practice, should encompass two important aspects: 1) conceptual and 2) epistemological. Many teachers define "inquiry" or "scientific practice" as mere problem-solving activities or hands-on activities that require high-level thinking (Kang et al., 2008). Traditional laboratory activities are typical examples. Some laboratory experiences are not necessarily fields of inquiry but are comprised of activities designed to verify facts and principles already learned. Their advantages include evoking interest in science from students through the process of replicating the experiment that scientists conducted, or of directly manipulating or experiencing something related to science, but multiple studies have proved that these kinds of traditional laboratory activities are not remarkably different from teacher-centered, lecture-based methods of instruction in terms of the degree to which they influence conceptual learning. The specific actions or processes that scientists perform while doing science should not be the focus of the classroom, but rather a teacher should pay attention to the type of reasoning scientists use when attempting to explain natural phenomena. By engaging in the process of scientific reasoning that develops knowledge, with a view to explaining natural phenomena, an understanding of scientific knowledge can be developed. In short, conceptual understanding of scientific knowledge should be emphasized throughout the practice of science.

On the other hand, Duschl and Osborne (2002) claimed that the practice of science should involve how scientific knowledge is formed and how it holds accountability. Instructions that emphasize epistemic discourse are successful in supporting students' development of epistemological ideas about science (Rosebery, Warren, & Conant, 1992). What distinguishes science from other disciplines is that the knowledge formulated by scientific practice is designed to explain the behavior of nature. Explicitly, any knowledge constructed by scientific methods cannot be regarded as accountable unless it accounts for the behavior of nature. In this context, scientific practice should be seen as epistemological practice and reflect the epistemic nature of science: construction and critique of arguments that are held accountable to evidence.

Central to the various forms of constructivism is the notion that students should build an understanding by considering the relationship between new information and their prior conceptual frameworks. Since the transmission theory of instruction (rote-learning theory) is still applied in too many classrooms, a constructivist learning theory generally places great emphasis on student authority. Nevertheless, the construction of knowledge has been overemphasized by teachers without sufficient attention on critique of the ideas (Ford, 2008). In many constructivist classrooms, students are the judge of knowledge and in turn, there is no way to determine how one explanation is better than an alternative (Osborne, 1996). Windschitl (2002) points out that teachers tend to face pedagogical dilemmas regarding whether they would allow students to make their own sense of nature that is not scientifically accepted or would didactically explain the scientific account. To avoid this problem, the classroom must emphasize the critique of arguments and disciplinary accountability. Basically, the construction of knowledge and authority should be emphasized, so students come to know that "scientific knowledge is held accountable by explicit connections to nature"—the epistemic nature of science (Ford, 2008). Therefore, teachers should create environments for scientific practice in which students engage in both the construction of arguments and the critique (evaluation) of arguments.

Social Dimension

In an effort to comprehend scientific practice, it should be noted that scientific knowledge is the product of social communities: scientific practice is socially constituted in nature. Scientists formulate knowledge by communicating with other scientists, shaping an accountable idea through validation and argumentation, in the scientific community. Additionally, from a socio-cognitive perspective, learning can be seen as a process of apprenticeship for social practice. Examining the aspects of classroom discourse based on the premise that learning is a social activity, the focus of classroom discourse can be characterized differently, depending on the weight given to the teacher's authority (power). In other words, the pattern of classroom discourse may be determined by which side has more authority (power), the student or the teacher.

In this social practice, language plays a critical role. Fundamentally, science cannot exist without language (Gee, 2004; Hand, 2008; Norris & Phillips, 2003). Scientists communicate through different forms of language, including written text, various modes of representation, and verbal discussion, to participate in a community for developing scientific ideas. This central role of language in scientific practice has received a growing attention from science educators. Cavagnetto (2010) claimed that language in scientific practice drives the epistemic nature of science and captures the culture of science. This attention stems from the basic notion that there should be parallels between the process of learning science in classroom and the process by which scientists construct knowledge (NRC, 1996).

In traditional, teacher-centered, classrooms, teachers are in charge of the classroom discussion. However, the student-centered approach requires that students engage in a public community and share their ideas. In this regard, students must have opportunities to talk with each other in small groups, with their peers as a whole group, and with the teacher. In elementary science classrooms, small groups allow students to share ideas and publicize their understanding of terms so peers can work toward a common understanding (Kutnick & Rogers, 1994).

Taking all these ideas together, the social practices in a science classroom are characterized/shaped by two different modes: 1) language mode (e.g. talking, writing, and reading mode) and 2) group mode (e.g., individual, small group, and whole group mode). These will be the focus.

Physical Dimension

Physical dimension focuses on how teachers use physical elements of science practice, such as time and materials, to support construction of the learning environment. Since science practice involves "measuring, framing, and representing nature's behavior" (Ford and Forman, 2006), it is important for students to access appropriate resources throughout the scientific practice. This dimension is fundamentally related to providing students with sufficient time or providing sufficient access to sources of information and materials.

Providing sufficient time is fundamentally related to teachers providing time for students to deal with ideas in depth (Collins, 1998). To engage students in digging deep into concepts through doing science, teachers should provide students enough time for each practice. Teachers should also remember that the focus of practice should not be covering books but rather the building an understanding of big ideas.

Another material component that needs to be noted is resources. Since scientific practices are conducted with different kinds of physical materials, such as experimental instruments and books, providing access to sources of information is critical for doing science. Therefore, curriculum materials should be designed to provide sufficient access to these sources.

Argumentation in Scientific Practice

The new NRC framework (2012) outlines eight scientific practices as the aim of science education (NRC, 2012, p.42): 1) asking questions (for science) and defining problems (for engineering), 2) developing and using models, 3) planning and carrying out investigations, 4) analyzing and interpreting data, 5) using mathematics and computational thinking, 6) constructing explanations (for science) and designing solutions (for engineering), 7) engaging in argument from evidence, and 8) obtaining, evaluating, and communicating information.

Although the new framework uses different language, the practices introduced by this standard share the fundamental nature of scientific practice with some inquiry models, such as argument-based inquiry. The argument-based inquiry model involves argumentative processes that construct claims by interpreting data as sound evidence and debating those claims with peers. As Dusch and Osborne (2002) assert, "teaching science as a process of enquiry without the opportunity to engage in argumentation … is to fail to represent a core component of the nature of science or to establish a site for developing student understanding" (p. 41). In other words, students need to engage in the argumentative processes that scientists undertake when they construct valid knowledge in scientific practice.

Immersion-Oriented Argument Based Inquiry (ABI)

Ohlsson (1995) described discourse as the medium of students' conceptual understanding and suggested four kinds of epistemic practice in discourse: describing, explaining, predicting, and arguing. In science education, scholars have paid most attention to argumentation as a powerful mechanism with which students can construct and develop new meanings collaboratively (Ohlsson, 1995).

Argument can be viewed as a special form of language that is produced through practice. Many scholars have been interested in how valid arguments can be constructed in the science classroom (e.g., Erduran, Simon, & Osborne, 2004; Hand, 2008). There exist at least two distinct perspectives about the approach. Some argue that this language (argument) should be learned before practice, while others believe that this language should develop naturally through practice. Cavagnetto (2010) classified the former perspective as a structure-oriented approach, referring to the latter as an immersion-oriented approach.

Halliday and Martin (1993) supported first approach, emphasizing that students need to familiarize themselves with the structure of the genre 'science' as a precursor for doing science. In other words, argument does not naturally develop through practice. They claimed that argument is a form of discourse that needs to be explicitly taught (through the provision of suitable activity, support, and modeling) repeatedly and explicitly stressing the significance of teaching the structures of argument. Considering that their perspective on language was reflected in their approach, it seems clear they view language as a representation tool. In their position, argument (language) is a decontextualized structure for the sake of scientific practice. If this structure is to be explicitly taught regardless of the context, argumentative structure can be taught through repetitive practice as we learn skills. As a consequence, teachers should separately teach different kinds of argument structures and skills for particular contexts.

On the other hand, the immersion-oriented perspective can be supported by Gee (2004), who insisted that language should be constantly formed in a context embedded in the learning experience and practice. If argument is a form of language that results from arguing, learning science through argumentation can be compared to the process of learning a new language. Gee (2002) explained that the learner accepts new language practices in terms of four sequential conditions. The learner perceives a new language used in a certain context, and may recognize why this new language is used, and begins to peripherally use it in conversation for himself or for herself. Subsequently, he or she will employ the language to perform specific meaningful activities. Finally, the learner needs to go through a process in which they can test their own presumed presentations and meanings of language to find out whether they work properly. At this stage, the learner solves new problems by voluntarily making use of this language and even transforms it to create a new kind of meaning in new situations. According to this perspective, argument will develop through practice, and the advanced argument appears in the form of outcomes of students' conceptual understanding. In this position, language is viewed as an epistemological tool for it has been used as a means to develop meanings in a context. Hand, Lawrence, and Yore (1999) said that the learner constructs knowledge through writing, and that writing functions as an epistemological tool when he or she understands what is counted as evidence.

Numerous lines of study have been conducted from these two approaches about argumentation practice in classroom discourse, and debate continues about the best ways to use argumentation practice to form science discourse that improves classroom learning in science. However, it seems more reasonable to conceptualized language (argument) as an epistemological tool, rather than view it as a value-free representation tool or structure, to enhance learning in science. A number of reform documents have continuously emphasized scientific literacy as the outcome of learning (American Association for the Advancement of Science, 1993). Scientific literacy goes beyond the perception of knowledge and process related to science; it includes the value and belief of science with regard to what is counted as knowing in science and which one is more valuable. If educators view argument as a value-free structure, epistemological nature and values of science should be taught separately. Cavagnetto (2010) asserted that, "argument is more of a product of inquiry than an enmeshed component of inquiry" (p.352). He also concluded that only immersion orientation can effectively capture the epistemic nature of science. Moreover, the immersion-oriented perspective is well aligned with the notion of the new NRC framework (2012). The new framework emphasizes that, "As in all inquiry-based approaches to science teaching, our expectation is that students will themselves engage in the practices and not merely learn about them secondhand. Students cannot comprehend scientific practices, nor fully appreciate the nature of scientific knowledge itself, without directly experiencing those practices for themselves" (p. 19). By taking this into consideration, this study aims to outline a framework of instructional practice by closely examining successful classroom practice that reflects an immersion-oriented ABI.

Summary

In this literature review, personal epistemology was considered as an important belief that influences learning and teaching. Epistemological beliefs, in this study, refer to beliefs about the nature of knowledge and knowing. Although numerous studies have demonstrated that epistemological beliefs played a critical role in teaching and learning, it was revealed those studies lacked a universal definition and use of different labels and paradigms. To rectify these issues, this study aims to construct a new concept: Epistemic Orientation toward Teaching Science. With this concept, this study encompasses four major teacher beliefs including both domain general and specific epistemological beliefs and beliefs about learning and teaching, to depict a bigger picture of how these beliefs inter-relate to each other and how the set of beliefs influence the instructional decision-making process. Through the literature review, seventeen distinct beliefs were recognized as potential dimensions of the EOTS, and these dimensions are to be refined and confirmed throughout the study. To examine instructional practices that incorporate critical aspects of science practice, multiple dimensions of science practice were defined through a literature review. These three dimensions of science practice are 1) cognitive, 2) social, and 3) physical.

CHAPTER THREE

METHODS

The purpose of this chapter is to establish the methodological framework for the study as well as identify the data collection and analysis procedures, and the trustworthiness, and limitations. The methodological issues addressed in this chapter include 1) the research design, descriptions of the data collection methods, and methods used to analyze teachers' Epistemic Orientation toward Teaching Science (EOTS); it also addresses 2) the three dimensions of practice and the intersection between (1) and (2).

Qualitative Research and Philosophical Assumptions

Qualitative research is based on the philosophical foundations of constructivism. According to Guba and Lincoln (1989) constructivists acknowledge multiple realities and that these realities are co-constructed by the researcher and participants within the participants' natural setting as collect data. As qualitative research, this study focuses on understanding teacher beliefs and practices, having no interest in predicting or controlling it. Instead, emphasis was placed on the natural setting, and the authenticity and trustworthiness of the data; no attention was given to whether or not the findings could be generalized in order to have meaning.

As the sole interpreter of the findings, I believed it is important for me to clarify my own worldview and maintain an awareness of how those beliefs affected my research. I will briefly explain my worldview based on four philosophical assumptions. First, I believe multiple realities exist about the central phenomenon as I embrace a constructivist viewpoint (ontological assumption). Those realities were co-constructed by the participants and myself throughout the study. The participants' language and direct quotes were woven into thick, rich descriptions, to provide readers with a truthful interpretation of their perspectives. Second, I immersed myself in the realities of my participants through close interactions (epistemological assumption). I visited the participants' sites at least once a week, and prior to the site visits, I always communicated through e-mail with my participants, to build trust and foster a warm, positive rapport prior to the interviews and observations. Third, I acknowledge that I had developed strong values related to the teachers' epistemological beliefs and practices before I conducted the current study (axiological assumption). I believe it is important to avoid injecting my beliefs into the perspectives of the participants by acknowledging these values. Lastly, as a researcher, I used an inductive approach (methodological assumption). I began the study with broad, general research questions; and allowed those to evolve while the study ensued. My broad research questions focused on how induction processes addressed teachers' essential beliefs that might be used when teaching science. I maintained an inductive approach through by using open-ended questions in my interview protocol. Through this approach, knowledge was developed and evolved, moving from particular to general.

Research Design

To provide insight into teacher EOTS and practices, this work adopted a multiple case study design that described and compared the cases of exemplary teachers (Creswell, 2007). Case study and qualitative methodology is preferable to other methods when researchers have little control over the events, and when the research is an attempt to understand a particular phenomenon in a real-world context (Yin, 2003). Case study was essential for the research described here because the main question asked how teachers' various beliefs shape EOTS and how those beliefs are related to teacher practice. Moreover, the aim of this study was not merely to document certain instructional practices, but also investigate how the many dimensions of science practice were incorporated to create classroom learning environments over time.

Case-study research is considered inductive in nature because each case offers insight within its own natural context. Yin (2003) defines case study as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident" (p.13). Although the definitions and types of case-study research vary, central to this form of research is the detailed collection of information with very little or no control over the circumstances (Merriam, 1998; Yin, 2003). Indeed, case-study research can provide in-depth descriptions and analyses of real-world events, as pointed out by Merriam (1998) and Yin (2003).

A case study is a form of interpretive research, like other forms of qualitative research (Merriam, 1998; Stake, 1995). Specifically, a multiple case study involves the use of more than one case for an investigation (Merriam, 1998; Yin, 2003). Consistent with this design, the study described investigated an issue through three cases, bound by time and space (Creswell, 2007)—specifically, the instructional practices of three experienced elementary teachers who have been implementing an Argument-Based Inquiry (ABI) approach successfully in their classroom. To build a better understanding of the three cases selected, information was collected from several sources, including four or five interviews, five weeks of classroom observation, teaching materials, and field notes. Figure 4 outlines the research design of the study.

The multiple-case study design allows the three cases to be compared and contrasted, and so should give more power to the ultimate conclusions. This approach will be taken following the recommendations of Yin (2003): "even if you can only do a 'two-case' case study, your chance of doing a good case will be better than using a single-case design" (p.53). The main goal of this study is to identify the core elements of EOTS that are shared by experienced teachers who successfully implement instructional practices that align well with features of scientific practices; and by comparing and contrasting six teachers' beliefs and thoughts related to how students "come to know," this study aims to identify teacher thoughts and beliefs that are closely associated with instructional practices that engage students in scientific practice.

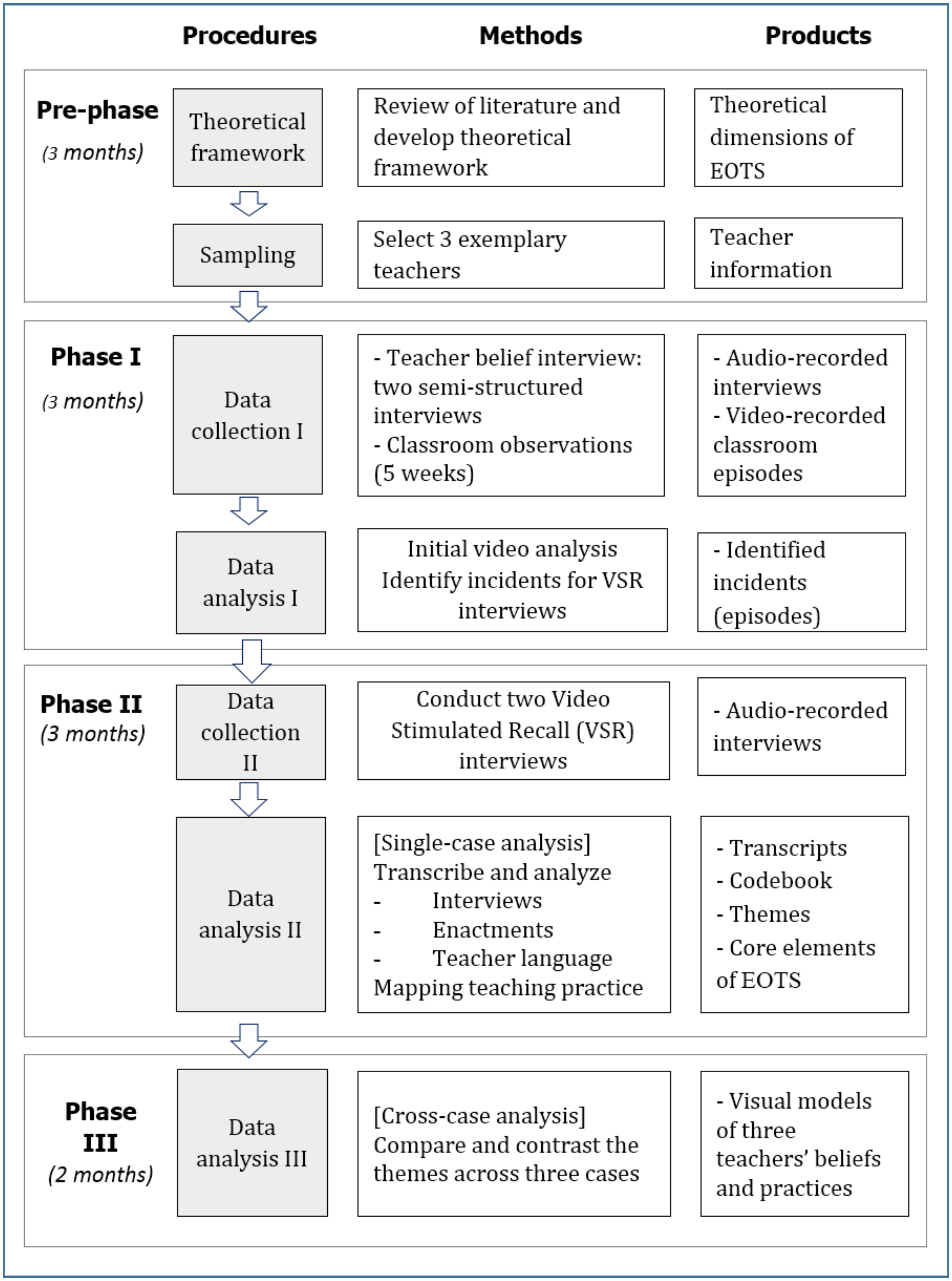

Figure 4. Design of the Study

The collection and analysis of data for this study were conducted in three phases (see Figure 4). The first and second phase focused on a series of three, single-case studies. Specifically, the first phase involved two interviews and five weeks of classroom observation. Incidents were identified for Video Stimulated Recall (VSR), interviews by an initial phase in which video-recorded classroom practices were reviewed. The second phase included two VSR interviews for each teacher. In this phase, classroom practices and interview data were analyzed at different levels. In the third phase, the three cases were compared and synthesized via the study's theoretical framework.

Participants

Three experienced and exemplary elementary teachers participated in this study. Participant selection was guided by purpose, which was to identify the core elements of the EOTS that influence classroom instruction for teaching the practice of science, and to understand how those core elements are related to various dimensions of science practice. Since this study aims to include exemplary teachers, who understand the critical features of science practice and implement it in their own classroom, the three cases were selected by purposeful sampling. According to Patton (2002), "the purpose of purposeful sampling is to select information-rich cases whose study will illuminate the questions under study" (p.169). Specifically, the three cases were purposefully selected using three criteria: 1) teachers who have been implementing an Argument-Based Inquiry (ABI) approach for at least three years, 2) teachers who have sustained core features of the ABI approach at least 2 years after Professional Development (PD) supports ended, 3) teachers who have been recognized as high implementers by a PD leadership team, and have demonstrated a high level of implementation of the ABI approach consistently as rated by the Reformed Teaching Observation Protocol (RTOP) (Sawada et al., 2002).

First, selecting teachers that had been implementing the ABI for at least three years was the key criterion that enabled me to recognize teachers who understood the nature of science practices and were able to engage students in these practices in the classrooms. From the standpoint of my study's theoretical framework—called the Science Writing Heuristic (SWH) or ABI approach—their instructional practice was considered as an effective approach that inherently encompassed key features of science practices. The key features include generating questions, constructing evidence-based claims, and participating in argumentation. Hence, this study assumed that the teachers who have been implementing the ABI would understand the theoretical foundation of science practice and how to incorporate key features of science practice into a cohesive instruction.

In addition, this study selected teachers who had used this approach for at least 3 years, which I believed is substantial amount of time for rearranging their knowledge bases and practices enough to be able to successfully implement this approach. Guskey (2002) argued that a teacher learning to be proficient in something new is a gradual and difficult process that demands time and effort. Moreover, if teachers are novice in implementing this approach, their lack of experience or lack of knowledge could become a more relevant variable that shapes their instructions rather than their beliefs and thoughts. Indeed, it was found that teachers needed to spend at least 18 months before they fully adopted the SWH approach (Martin & Hand, 2009).

Secondly, teachers who have sustained the key features of the SWH at least two years after PD ended were purposefully selected to reduce external factors that might affect their willingness to implement the approach. Considering that instructional practices could also be affected by various external factors, such as PD supports, school policies, and monetary rewards, this study intended to select teachers who are internally driven and voluntarily implement the approach even after PD supports ended.

Thirdly, teachers who demonstrated high implementation of the SWH approach were selected because the study aimed to scrutinize exemplary cases of using science practice, as a way to provide insight into how these practices look in a real-world science classroom. Previous studies demonstrated that a teacher's level of the implementation of the SWH approach is positively related to the teacher's modified RTOP score (Cavagnetto, Hand, Norton-Meier, 2010; Martin & Hand, 2009).

To identify potential participants who met all these criteria, I consulted with the research team that had coordinated and led the SWH PD program for in-service teachers. Information regarding years of implementations on the ABI approach, teacher implementation scores rated by the modified RTOP during the PDs, and their students' Cornell Critical Thinking Test (CCTT) scores was collected to determine candidates. Through the consultation, nine potential teachers were selected. To confirm their implementation level, their video-recorded classroom practices were reviewed and scored again by the modified RTOP. Unfortunately, however, only two teachers were consistently rated as high implementers by this scale. Thus, the teachers who were rated at a medium-high level were also included.

Among the potential teachers, in addition, only those who indicated a willingness to participate were considered for the study. Access to each teacher was gained through their principal, receiving permission to speak with potential cases about the nature of the research and the time required for the investigation. As a result, six teachers out of nine were selected and five of them agreed to participate. Although data was collected from all five teachers, this study included only three teachers because, at the time, they were teaching the same science topic at the same grade level. Table 4 presents background information on the three participants. For confidentiality, all were given pseudonyms.

Steve is white male who had 14 years of teaching experience at the time of the study. He had been trained to implement the SWH for the past three years (2007-2010). The PD workshops had aimed to help teachers implement the SWH to promote student learning in science classrooms. Steve has been invited to lead PD workshops several times and consistently demonstrated a high level of SWH implementation. His students' CCTT scores had been much higher than control groups' scores, every year. In the year of this study, his students' growth scores in CCTT averaged 6.42 points. Tseng (2014) reported that students in classes where teachers successfully implemented the SWH approach improved their critical thinking skills over the school year (n=741, mean growth score =4.63) more than students in classes where teachers used a traditional approach or implemented the SWH approach at lower level (n=859, mean growth score =2.55).

Table 4. Background Information of the Teachers

	Steve	**Janet**	**Wilson**
Gender	Male	Female	Male
Age	30-39	30-39	50+
Education	B.A.	B.A.	B.A.
Number of science courses taken at college level	3	3-4	1
Years of teaching	14	11	30
Teaching grade level at the time of the study	5th grade	5th grade	5th & 6th grade
Years of implementing SWH	8 years	8 years	4 years
Years of training by PD programs	3 years	3 years	3 years
Years of implementing SWH after PDs	5 years	5 years	1 year
Level of implementation while participating in SWH PD programs	High (3.5-4.0)	High (3.1-3.6)	Medium High (2.7-3.2)
Science lesson taught at the time of the study	4-5 lessons/week (60-65 minutes)	4-5 lessons/week (50-60 minutes)	4-5 lessons/week (30-50 minutes)
Science topic taught at the time of the study	Force and motion	Force and motion	Force and motion
Student growth scores in Critical Thinking Test (2013-2014)	6.42 point	4.04 point	N/A

Janet who is a white female teacher, with 11 years of teaching experience, also had been trained by the SWH PD program for three years (2007-2010), and also was several times invited to lead SWH PD workshops. Similar to Steve, she had shown fairly consistent implementation of the SWH approach, at a high level, and her students' growth scores in CCTT were much higher than the control groups' growth scores. At the time of study, her students' growth scores in CCTT averaged 4.04 points. Wilson, a white male, had the most teaching experience (30 years) at the time of this study. Like Steve and Janet, He had been trained through the SWH PDs for three years (2010-2013) and shown fairly good level of implementation of the SWH approach (i.e., average to medium-high. Although he was the most experienced teacher among the three participants, his experience using the approach was the briefest. His students' growth scores in CCTT were not available for the year of this study.

School Context

This study was conducted at two different schools in the Midwestern United States. Steve and Janet were working at the same school. The school was located in a rural area with a population just over 10, 000. The whole school district served over 2000 students; and the intermediate school at which Janet and Steve were working served around 490 students, in grades fourth through sixth. There were three fifth-grade teachers who had been working collaboratively to design their school curriculum. During the 2013-2014 academic year, the ethnic diversity of the student population at the school was around 90.6% White, 4.7% Asian American, 2.7% African American, and 1.2% Hispanic.

The second school's site was also in a rural area, 16 miles east of the first. The whole school district served over 500 K-12 students. During the 2013-2014 academic year, the student enrollment in elementary school was total 295 and the ethnicity diversity was 98% white, and only 2% others, including American Indian/Alaska native, Asian, and Hispanic. There were two 5th grade teachers who were working together to design their school curriculum.

Data Collection

Triangulation was employed for the research design, to sustain validity, so data was collected via several methods. Denzin (1978) emphasizes the rationale for this methodological triangulation strategy by explaining that "the flaws of one method are often the strengths of another, and by combining methods, observers can achieve the best of each, while overcoming their unique deficiencies" (p. 308). The main data sources for this study were four to five interviews with teachers, and video-recorded teaching practices. Although students' science notebooks and their final classroom projects were also collected, those served only for triangulation purposes because the focus of this study was not to examine the effect of teaching on students' learning, but rather, to examine how teachers support student learning through science practice. Data were collected over approximately 11 weeks during the 2014 Spring semester. Table 5 outlines the research questions of the study and the methods used to address each.

Table 5. Data Sources and Research Questions

Data Source	Data collection for each case		Q1*	Q2**
Teacher Beliefs Interviews	2 interviews (1hour/each)	Before classroom observations	X	X
Classroom Observations	10-12 lessons (3 weeks)	5 weeks selected by a teacher	X	X
Video Stimulated Recall (VSR) interviews	2 interviews	After classroom observations		X
Artifacts	Lesson plans, student notebooks, classroom materials, and etc.	Every week	X	X

*Q1: What are the core elements of a teacher's EOTS that all three teachers strongly held in common?

**Q2: How are the core elements of teachers' EOTS related to the three dimensions of instructional practices: the epistemological, social, and physical dimensions?

Semi-Structured Interviews

Interview is one of the most useful methods for revealing the meaning of people's experience and their world as they experience it (Kvale, 1999). In classroom observation, interviews can provide access to the context of students' action (Seidman, 1998), and thereby the researchers can get the story behind teachers' and students' actions. In this respect, interviews will be used in this study to probe what teachers understand and believe, and why they select specific instructional methods for creating a learning environment that will foster students' participation in scientific practice. To gain an in-depth understanding of teachers' background, their epistemological beliefs, and their beliefs and thoughts about student learning and teaching, two types of interview will be conducted: (a) a teacher-beliefs interview; and (b) a video-stimulated, recall interview. Sample questions of each interview are presented in Table 7 (see Appendix A for full interview questions) and the total amount of data collected by interviews is presented in Table 6.

Table 6. Data structure by Each Teacher

Type of data sources	Steve	Janet	Wilson
Teacher Beliefs Interviews	2 interviews total 2.5 hours	3 interviews total 2.2 hours	2 interviews total 2.1 hours
Classroom Observations	31 lessons 60 mins/lesson	25 lessons 45 mins/lesson	19 lessons 35 mins/lesson
Video Stimulated Recall (VSR) interviews	1 interview Total 2 hours	2 interviews Total 1.75 hours	1 interview Total 1.5 hours
Artifacts	Student notebooks Student worksheets	Student notebooks Student worksheets	Student notebooks Student worksheets

Teacher-beliefs interviews.

This portion of the interview process collected information on the participants' beliefs and thoughts about knowledge, learning, and teaching. Two or three interviews were conducted based on each teacher's schedule, and each took an hour at most. The entire interview was recorded and field notes were taken during the interview. In the first phase of data collection, two or three semi-structured interviews were scheduled and participants asked a series of open-ended questions designed to determine their thoughts and beliefs about knowledge, student learning, and teaching. To determine the beliefs and thoughts of science teachers, the interview questions were based on a review of literature on teacher beliefs. Since conceptualizing and identifying beliefs can prove difficult for the interviewee, the semi-structured interview protocol was used to provide structure (Kagan, 1992; Pajares, 1992). When necessary, follow-up questions clarified comments or provided additional details regarding teachers' beliefs and thoughts. Participants were asked to check their responses in transcripts of their interviews and observation field notes.

Video-Stimulated Recall (VSR) Interviews.

The present study used stimulated recall (SR), an effective technique for examining teachers' thoughts, decisions, and reasons for acting. One of the assumptions in using the SR technique is that teachers have some degree of access to their professional thinking, which can be represented in words (Calderhead, 1987). Through the video-stimulated recall (VSR) technique the study was able to explore and evaluate teachers' observations and commentaries regarding their actions. Stimulated recall has been extensively used in research into teaching (e.g. Housner & Griffey, 1985; Butefish, 1990; Tjeerdsma, 1997) and continues to be popular. It is the most inclusive way of studying classroom phenomena (Pirie, 1996) and allows teachers to relive an episode of teaching, by providing a retrospective, accurate, verbalized account of their thought processes (Calderhead, 1981).

Table 7. Examples of Teacher Beliefs Interview Questions

Pre-instruction interviews: Teacher beliefs	
Nature of Knowledge and Knowing in General	Do you believe that knowledge is definitely unchanged or changed with time? What cause you to have such a belief?
	The best ideas are often the simplest. On the flipside, are the best ideas the most complex? What do you think?
	Could you explain where your knowledge came from? Is your knowledge mainly coming from authorities or self-construction?
	Do you agree that the content of textbooks is in general correct and highly believable?
Nature of Knowledge and Knowing in Science	What is science? What makes science different from other disciplines of inquiry (e.g., religion, philosophy)?
	Sometimes people argue that 'scientists are searching for truth'. What do you think about this statement?
	Scientists perform experiments/investigation when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?
	What role does evidence play in learning science?
Beliefs about Learning	How do students learn? Can you give an example of how this looks in your classroom?
	In science class what are the students' role in the learning process?
	How do you know when your students are learning?
	How do you believe students learn science best?
Beliefs about Teaching	What type of materials and activities do you use to support learning in your classroom?
	In science class what is your role as a teacher in the learning process?
	In your opinion, what are the goals of teaching science?
	Do you believe that argument-based inquiry approach helps students to learn better in science?
Post-Instruction Interviews: General Instruction & Video Stimulated Recall	
Reflection & Reasoning	What do you think about this instructional session?
	Do you think your student learned science as you intended throughout this lesson? How do you know?
	How did you decide what to teach?
	How did you decide what to ask your students?
	Can you give me an example of how evidence was emphasized in your lessons?
	Why did you choose_________approach to help student learn science?
	How would you like to modify your lessons if you teach this unit again?

Before conducting VSR interviews, all video-taped classroom practices were reviewed and roughly coded according to eight science practices addressed in NGSS. Through the initial analysis, eight video-taped lessons were purposefully selected for each teacher. Initially, videos were selected by two criteria: 1) the taped lesson should include teaching segments representing at least two of eight science practices, and 2) the taped lesson should include teaching segments reflecting at least two of three dimensions of science practice (cognitive, social, and material). Among the videos selected by these criteria, the eight that collectively captured eight practices of science were selected for each teacher. Table 8 shows the types of science practice that were reflected in each of eight lessons for each teacher (see Appendix B for the topic of each lesson). These eight videos were used for the VSR interviews and further data analysis on teacher enactments and dialogical interactions.

Table 8. Selected Lessons by Science Practices

	Steve	**Janet**	**Wilson**
Lesson 1	P2, P3	P1, P7	P1, P3
Lesson 2	P4, P6	P4, P6, P7	P4, P6
Lesson 3	P6, P7	P1, P2, P3	P6, P7
Lesson 4	P6, P7	P6, P7	P1, P3, P4
Lesson 5	P3, P4, P6	P6, P7	P5, P6
Lesson 6	P2, P3, P4, P6	P2, P3, P5	P2, P3
Lesson 7	P3, P6	P2, P3, P5	P6, P7
Lesson 8	P2, P4, P6	P2, P4, P6	P6, P7

Science Practice
P1: Asking questions
P2: Developing and using models
P3: Planning and carrying out investigation
P4: Analyzing and interpreting data
P5: Using mathematics and computational thinking
P6: Engaging in argument from evidence
P7: Obtaining, evaluating, and communicating information

In the second phase of data collection, participants were asked to view the videotaped teaching episodes. The VSR interviews were conducted once or twice and involved the teacher and the researcher watching the video-taped instruction directly from a computer or TV screen. These interviews were scheduled two weeks after collecting all classroom videos. The incidents were identified based on video analysis by the researcher. During the interviews, each teacher watched a portion of video and was asked to reflect back on their actions. While watching a video clip, they could pause the video by themselves; and, if they could remember the day of that particular lesson, could go back. The teachers viewed each lesson for average 5-7 minutes and the whole interview lasted around 1.5 to 2 hours. Teachers were allowed to end the interview or prolong it, as they wished. During the VSR interviews, teachers were also asked to respond to questions that focus on teacher reasoning behind their instructional practices. As they watched the video of their instruction, the teachers responded, based on their recollections of their thoughts and actions. This VSR interview technique is "among a family of introspective research procedures through which cognitive processes can be investigated by inviting subjects to recall, when prompted by a video sequence, their concurrent thinking during that event" (Lyle, 2003, p.861). This method provided the opportunity for the researcher to clarify or probe observations made during the second phase of data collection.

Classroom Observations

To document the instructional practice of the teachers, during the first phase of data collection, each teacher's classroom was observed for five weeks by field notes and a video recorder. Data were collected mainly via observation because observation can confirm what is reported in an interview (Patton, 2002), and also, observation provides the "opportunity to record information as it occurs in a setting and to study actual behavior" (Creswell, 2005, p.211). The classroom observation allowed me to investigate the teachers' enactment of their decisions and beliefs, and dialogical interactions with their students.

Classroom practices were captured by non-participatory observation methods. "The nonparticipant observer is an 'outsider' who sits on the periphery or some advantageous place (i.e., the back of the classroom) to watch and record the phenomenon under study" (Creswell, 2005, p.212). As a nonparticipant observer, I visited at least one lesson per week, for each teacher, and took field notes and videotape the lesson, without becoming involved in the practice of the teacher and students. To capture the entire process of the science practice, each teacher's science classes were videotaped by the teacher every week for three to four class sessions. A video camera was installed at the corner of the classroom to record the whole classroom's activity. These practices included, but were not limited to, eight practices of science and SWH approach's five phases: beginning ideas, test/observation, claim and evidence, reading, and reflection. In addition, to capture the teachers' voices clearly, each wore a microphone every time.

All classroom visits were pre-arranged and focused almost exclusively on classroom instructional practices. Since one subject unit was observed over the course of a semester, each participant was contacted by e-mail one week before the unit began, to confirm their class schedules and their current teaching assignment. Every week, I met each teacher to discuss the observation protocols and address any questions they had. The field notes documented observations and reflections made during the class session.

Artifacts

Another important source of information came from analyzing each teacher's instructional documents, including lesson handouts and lesson materials and examples of student work. The purpose of collecting these documents was to complement the information from classroom observations and interviews. The use of these documents allowed data from various sources to be compared and contrasted. "The main advantage of this type of data collection is that it does not influence the social setting being examined" (Hatch, 2002, p.25). These artifacts were labelled with the teachers' pseudonyms, the data, and a letter code. Once collected and labeled, all artifacts were placed in the research data folders

Data Analysis

This research was designed to determine the themes that emerged from the three cases. In a multiple case study, "the researchers have an obligation to provide interpretation across the cases" (Stake, 2006, p.39). Thus, after analyzing each case separately, a cross case analysis was performed. The overview of the data analysis procedures is presented in Figure 5.

Data for single-case analysis came from multiple sources: (a) audio taped teacher interviews on their EOTS; (b) video tapes of teachers' instruction; (c) audio taped teacher VSR interviews; (d) research field notes; and (e) artifacts including classroom materials, and student notebooks. After analyzing these data sources for each teacher, themes were compared and contrasted, across the three cases and based on the following descriptive categories: teacher beliefs, planning, classroom enactments, and dialogical interactions. A text comparison chart visualized the relationships and created a systematic comparison across cases.

In this study, data were collected and analyzed simultaneously (Merriam, 1998). Framework Analyses (Ritchie & Spencer, 1994) were use used for single-case study. This approach is inductive in nature, but allowed both known and emergent themes to be included. The process involved five steps: familiarization, identifying a thematic framework, coding, charting, and mapping and interpretation of the data. The descriptions of the analysis procedures in this chapter present by each research question.

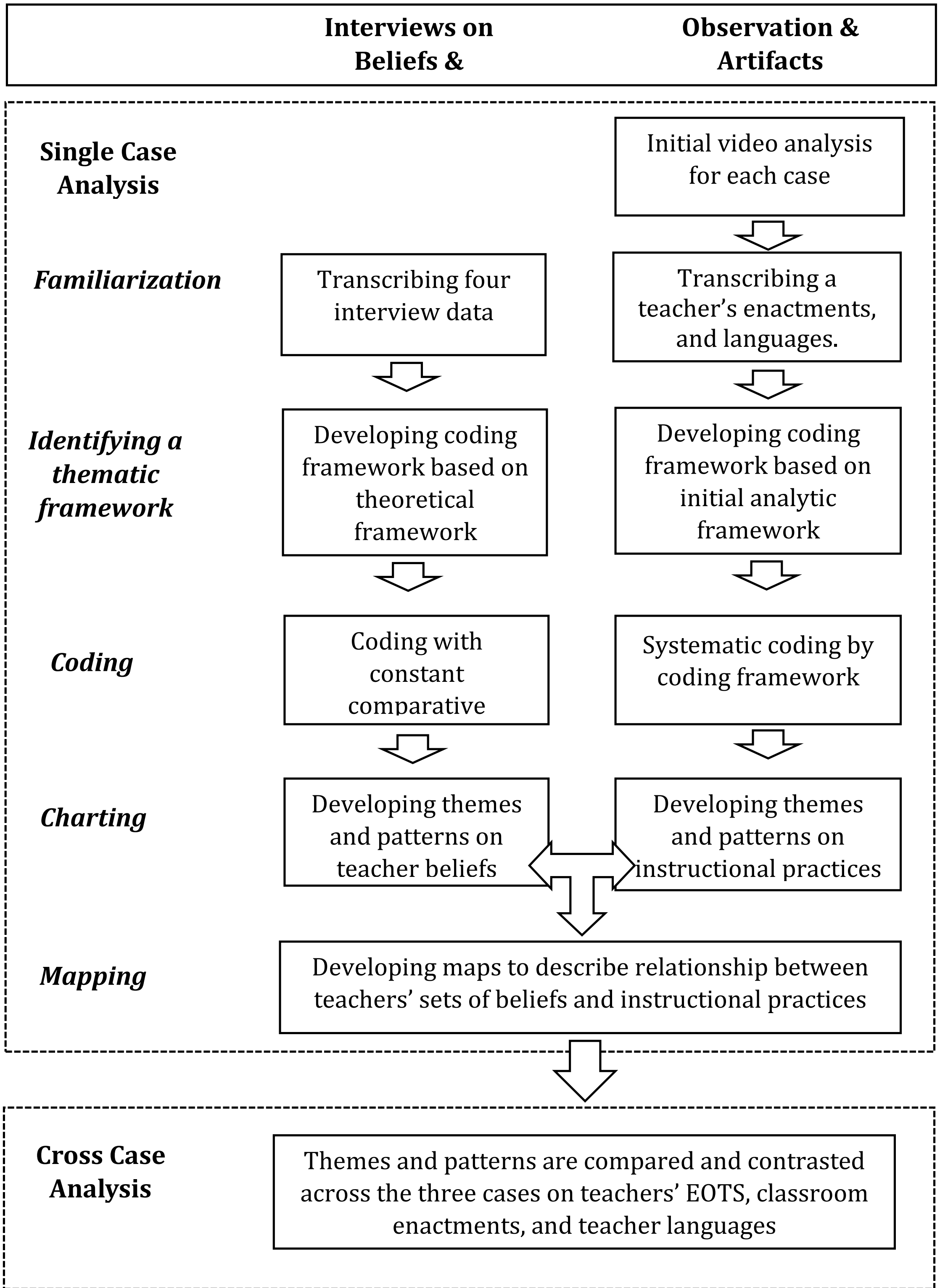

Figure 5. Outline of Data Analysis Procedures

Research Question 1: Analysis of Interviews

Familiarization.

The first phase of analysis began with the organization of the data, which occurs throughout the data collection phase and involves the verbatim transcription of interviews, the creation of typed lesson scripts from observations, and labeling of artifacts. All audio-recorded interviews were transcribed within two weeks of the interview. Once transcribed, interviews were e-mailed to teachers for review, clarification, and addition of any pertinent details. To prevent investigator bias, interviews were not analyzed until the observations were over.

Identifying a thematic framework.

For the semi-structured interviews, the thematic framework was set up before the interviewing began and continued throughout the analysis phase. After interviewing was completed, the initial coding framework was refined by reviewing both the interview transcripts and investigators' notes (taken during the interviews).

Coding.

The interview data were coded and analyzed with the aid of NVivo v.10 computer software. According to Creswell (2005), the use of computer analysis programs facilitates "the process of storing, analyzing, and sorting the data" (p. 234). The computer assisted coding of the interviews was conducted at two different levels. The First focused on identifying core elements of EOTS, and the second examined the interrelationship between the core elements.

Core elements of EOTS.

To identify core elements of EOTS, the coding and the interpretive analysis process for the first two interviews includes five steps. First, the initial coding framework of this study was designed through literature review. The first-level codes define 17 theoretical elements of EOTS (see Table 9). The coding system remained open to revision by changing the theoretical categories and adding any categories that emerged throughout the coding procedure.

Second, the initial coding framework began to be revised during the interview process. I generated field notes focused on the research questions. "The whole idea of making a record of impressions during the process of gathering and processing data is to capture potentially fruitful explanations that can be systematically examined later" (Hatch, 2002, p. 182). The researcher's field notes recorded during the interviews were reviewed first. Through the review, the information from the field notes was integrated into practical units and provided a foundation for the coding process. This process enabled me to refine and clarify the theoretical codes. Through this process, the code 'Control of Learning' was added.

Third, using the refined coding framework, the transcribed interviews were classified by each element of EOTS. After all interviews were coded, the coded references were gathered by each categories using NVivo. The data was read and revised several times to interpret each belief of the teachers.

Table 9. Initial Coding Framework

	Categories (1st level)
Epistemological Beliefs in general	Changeability of Knowledge
	Structure of knowledge
	Source of knowledge;
	Justification of knowing
Epistemological Beliefs in science	Open to Revision
	Order and Consistency
	A Way of Knowing
	Variety of Methods
	Empirical Evidence
	Models & Theories
	Human Endeavor
	Questions About the Nature
Beliefs about Learning	Ability to learn
	How to Learn
Beliefs about Teaching	Role of Teacher
	How to Teach
	Goal of Teaching
	*Control of Learning (emerged)

Fourth, a summary was drafted for each code that described key ideas about each belief. In total, eighteen summaries (for each of 18 codes) were generated for each teacher.

Fifth, Interpretations were reviewed with the participants. The main goal of this step was to ensure that participants agreed on the way their thoughts and beliefs were described and analyzed. To ensure that the data analysis was valid and reliable, member checking and peer debriefing were employed (Lincoln & Guba, 1985). This improved the likelihood that the data analysis was credible and consistent with what the participants had said and thought.

Interrelationship between beliefs.

To identify the interrelationship between each belief, a second-level coding was implemented. The second-level coding included three steps. First, it began with gathering the coded references by interview questions (whereas, in the first-level analysis, the coded references were gathered by code). Then, the teachers' answers to each question were reviewed and any that had more than two codes were collected. This study assumed that if any two codes were presented together within the same answer, then the beliefs were linked. For example, if there were three codes (A, B, and C) presented together while answering one question, it was assumed that there were three connections (A-B, A-C, and B-C). One should note that the number of connections for each code did not indicate strength, but rather just presented how frequently it connected with other elements.

Charting.

The next phase of data analysis involved developing graphical displays to represent the thematic framework of the data. The purpose of these charts was to reduce the data, to more clearly compare the datasets and note patterns. This process began with the creation of graphical displays depicting the relationship between each belief.

Mapping and interpretation of the data.

The final phase involved a synthesis of the charts and graphical displays into narrative accounts of the teachers' beliefs and thoughts about knowledge, science, learning, and teaching. The narratives, charts, and graphical displays were used to describe patterns within each case's data and among the data collected for all cases (Creswell, 2007; Ritchie & Spencer, 1994).

Research question #2: Analysis of Videos and VSR interviews

Familiarization.

Similar to the analysis of semi-structured interviews, the first phase of analysis began with organizing the audio-taped VSR interviews and videotaped lessons, and involved the creation of typed lesson scripts from observations, and artifact labeling. Once transcribed, the lesson scripts were e-mailed to teachers for review and clarification.

Identifying a thematic framework.

To identify incidents in the VSR interviews where an instructional practice needed to be clarified by the teacher, the videotaped lessons were initially reviewed and analyzed. After conducting the VSR interviews, the filed notes and videotaped lessons were converted into typed lesson scripts. Transcripts included the hour of day that each lesson segment began, descriptive notes of what occurred, and researchers' reflective notes. During the transcription of the lesson, themes and codes for instructional segments were based on the analytic framework, and this continued throughout the observation phase, as themes and instructional codes evolved. The coding framework was developed and refined during observations. For observations and artifacts, the thematic framework was initially conceptualized according to the study's theoretical framework (see Table 3). After the observation phase, the transcripts were read and reviewed, along with the lesson scripts and artifacts. As the analysis phase progressed, themes emerged from the observations and artifacts, so the framework needed to be refined.

Coding.

The theoretical coding framework was applied to the data, starting with the coded data on VSR interviews, observations, and artifacts. Coding was conducted during the creation of lesson scripts and completed for eight selected videotaped lessons of each case before the post-observation (VSR) interview.

To determine the themes existing and emerging in each lesson and how these relate to instructional practice, before coding, the lesson script was read and the artifacts reviewed. Since the study aimed to analyze classroom practice by a three-dimensional framework, three levels of codes were generated for each practice.

Initial analysis.

First, the data were read to gain an overall perspective. Then, the lesson format was coded based on the eight science practices (initial analysis). If a portion of lesson was not related to any type of science practice, it was classified as *management*. Each unit of science practice was coded and ranked, based on the percentage of instructional minutes devoted to it; and the instructional coding that occurred with the highest percentage during practice were used to code the practice.

Cognitive dimension.

The cognitive dimension of instructional practices was analyzed based on the coding framework, which had been designed during the initial states of analysis. The categories for conceptual aspect of practice included 'focus of learning (science practice or science concepts, or both)' and 'emphasis of big ideas,' while the categories for epistemological aspect included 'source of ideas (teacher-oriented or student-oriented)' and 'purpose of practices.' Each code was made by every turn taking in dialogue. That is, if there were 150 turns taken by either a teacher or a student, then there should 150 codes for this category. Finally, the science concepts and activities that were addressed in each lesson were summarized during data analysis.

Social dimension.

To examine how the teachers used different modes of language (e.g. talking, writing, and reading), each was coded every minute. For example, 60 codes for the language-mode category were made for a 60-minute-long lesson. Similarly, different modes of group work (e.g. individual, small group, and whole group) were coded every minute. In addition, the transition between different modes of practice was coded. When the mode of practice was changed by either language or group work, I coded it as 1, which indicates a transition. Table 10 shows an example of this coding system.

Table 10. Example of Coding for Social Dimension

	Language	Group	Transition
00:00:00	T	S	
00:01:00	T	S	
00:02:00	T	S	
00:03:00	T	W	1
00:04:00	T	W	
00:05:00	T	W	
00:06:00	W	I	1
00:07:00	W	I	
	T: Talking W: Writing	I: Individual S: Small group W: Whole group	

Physical dimension.

The teachers' uses of physical materials were analyzed and coded based on type. Through the analysis, five codes emerged: 1) science notebook/journal, 2) books, 3) resources from the Internet, 4) experimental tool/ materials, and 5) other. Summaries describing a way of using the materials were created for each teacher.

Dialogical interactions.

Teacher's dialogical interactions were analyzed using the initial coding scheme, as shown in Table 11 (see Appendix C for full version). The coding scheme was designed through the literature review for this study. The patterns of "teacher talk" were analyzed by three categories: 1) Type of talk (i.e., question or statement), 2) nature of talks (i.e., initiation or epistemic, and 3) function (i.e., question or statement)

To determine the essential elements that were reflected in instructional practices, the same coding framework created for the semi-structured interviews was used. While reading and reviewing the VSR interview scripts, each lesson was coded by the coding framework.

Charting.

The results of data analysis were represented by graphical display. The representations depicted the instructional practices of the lessons taught by each case. Teachers' individual instructional graphs were compiled to visually represent the instructional approach used over the entire period of observation.

Mapping and interpretation of the data.

Based on the graphical displays, narrative descriptions of three-dimensional instructional practices were generated. The descriptions included how the teachers incorporated these three dimensions into instructions and how their practices were different between each stage of instruction (i.e., planning, enacting, and interacting).

Table 11. Coding Framework for "Teacher Talk"

Categories	*Sub-categories*	Code	Descriptions
Type	*Question*	Q	Teacher asks questions
	Statement	St	Teacher provides statements
Nature	*Initiation question/statement*	Int	To start classroom discussions, introduce new topics, or elicit students' understandings related to concepts, events and situations yet to be addressed in the ongoing discussion.
	Epistemic question/statement	Epi	In response to students' previous contributions to classroom discourse for reactive purposes such as sustaining discussion on a particular topic, following up on ideas previously introduced by students, and requesting elaborations or clarifications from students

Cross-Case Analysis

After interviews and observations have been analyzed for each case, the summary results were compared and contrasted between three cases. Through reading and analyzing the summaries and visual representations, common themes for each code and category were identified. Based on the common themes, a summary for multiple-cases were drafted by beliefs, instructional practices, and the relationship between the two.

Trustworthiness

The concept of "trustworthiness," as introduced by Lincoln and Guba (1985), implies that a researcher must demonstrate that their findings are honest, meaningful, and credible and empirically supported (Patton, 2002) by controlling potential bias in design, implementation, and interpretation. To establish trustworthiness, Marshall and Rossman (2011) suggested three criteria: credibility, transferability, and dependability.

Credibility

Credibility is an assessment of whether or not the findings accurately represent the participants' experiences. To improve the likelihood that credible findings and interpretations would be produced through the data collection and analysis, this study used three methods.

Member checks are an essential technique for establishing credibility by questioning participants on the accuracy of their account (Creswell, 2005; Guba & Lincoln, 1985). By taking the data back to the participants, the researcher can confirm the accuracy of the information. In this study, I gave each participant verbatim transcripts of their in-depth interviews, to confirm that the data was a true representation of what they say and believe.

Peer review, or debriefing, is "a process of exposing oneself to a disinterested peer in a manner paralleling an analytic session and for the purpose of exploring aspects of the inquiry that might otherwise remain only implicit within the inquirer's mind" (Lincoln & Guba, 1985, p. 308). That is, it is a process in which colleagues, familiar with the research topic or the methodology, provide consultation and feedback. The role of the peer reviewer is to critically examine all aspects of the research process and to ask tough questions that prompt the researcher to explore the assumptions and interpretation of the data (Lincoln & Guba, 1885). I discussed the results of the data analysis with faculties and graduate students in the science education program and two graduate students in other programs, to explore researcher's bias and clarify the meanings and the basis for interpretations.

Triangulation is the process of corroborating evidence from different individual types of data or methods of data collection. By collecting data from several sources of information, such as multiple interviews, classroom observations and lesson plans, I, as a researcher, was able to get different perspectives on the same issue.

Transferability

Transferability is the degree to which the findings can be applied beyond the scope of the study. To establish transferability, we followed the Mosckovich and Brenner (2000) example of using two strategies: *thick description* and *purposeful sampling*. By providing thick descriptions of the context, data collection process, data analysis procedures and findings, readers were allowed to evaluate applicability of the present study. The purposeful sampling also provided the readers with an understanding of the rationale and procedures of sampling.

Dependability

Dependability is an evaluation of the integrity of the data collection and analysis as well as the interpretation of the data. To enhance dependability, details of the process of data collection, data analysis, and data interpretation should be documented. In this study, the detailed research process was logically presented, thereby other researchers outside the project can scrutinize the present study. In addition, all transcripts were coded by another graduate student who is in other area of the program. The differences in coding were resolved through discussion.

Summary

This study utilized qualitative methods to understand the critical elements of EOTS and the relationship between the essential elements and instructional practices. Sources of data used in this study included semi-structured interviews, Video-stimulated recall interviews, classroom observations, field notes, and various artifacts. For the data analysis, this study established each single case first and then compared and contrasted the themes, charts, and displays across three cases. Purposeful sampling strategies, member checking, and coding by outside researcher all helped enhance trustworthiness.

CHAPTER FOUR

FINDINGS

The purpose of the research is 1) to identify the core elements of the EOTS of three exemplary 5th grade teachers who were known to foster student learning through scientific practice, and 2) to examine the relationships between those elements and instructional practices. By focusing on similarities rather than differences of these teachers, this work seeks to identify the fundamental beliefs and thoughts a science teacher should develop to succeed like these exemplars. With this purpose, part I describes the core EOTS elements of the three teachers; and part II discusses how those beliefs guide their instructional decisions.

In part I, the analyses aimed to identify the beliefs critical to forming the expert teachers' epistemic orientation. Those beliefs were recognized using the three criteria: 1) they must be shared by the three teachers; 2) they must be compatible with the epistemological foundations of the current reform movement; and 3) they must be interrelated with the other beliefs. With the set of beliefs identified by these criteria, Part II describes how these beliefs influenced the teachers' instructional decision making when they were planning classroom scientific practice, implementing plans, and participating in dialogical interactions with students. Through the analyses, a conceptual model of EOTS evolved that captures the essence of teacher orientations necessary for effective science teaching.

General Characteristics of Each Participating Teachers

Before entering into the main findings, a description of each teacher is given with regard to their personality, instructional style, and classroom atmosphere in general.

First, Steve possessed a very quiet and calm personality. He talked very carefully and rarely spoke loudly even in interactions with his students. During the interviews, he spoke of his thoughts carefully and calmly, but an air of certainty and passion was always apparent. He was passionate about science and was confident about teaching it. Although he did not speak loudly during class, most of his students listened intently to him and interacted very naturally with him. He was stern and strict in terms of the students' behavioral problems, but since he created a learning environment where students could debate and share opinions themselves, the overall class atmosphere was very natural and dynamic. Most importantly, his students actively engaged in argumentation themselves even without his direction. During class, Steve's main role was to listen intently to his students' ideas and actively support any who had difficulties understanding a particular idea, by asking questions or by providing sufficient resources. At the center of all practice was argumentation; and Steve's classroom environment was very forward looking: an ideal image of a student-centered classroom.

In contrast, Janet always came across as always active and energetic. She used a relatively big and energetic "voice" and moved whilst speaking with the students. Students sat on gym balls rather than chairs, so a dynamic energy was always felt. Like in Steve's classroom, students in Janet's classroom decided their tasks themselves through discussion and Janet played a role of helping and assisting with those decisions. Whereas Janet handled students' behavioral problems strictly and kept reminding students to focus on their tasks, she empowered her students to do what they wanted when it came to conceptual learning. Moreover, she participated in argumentation at the same level as her students and often defined her role as an authentic learner. She pursued a different teaching style to Steve, but it was clear that her classroom practice was student-centered and argumentation was at the core of those practices, like in Steve's class.

Wilson was the oldest and the most experienced of the three teachers. Although he possessed a strong-minded faith about teaching (like most experienced teachers), he kept an open-mind. During the interviews, he often showed a willingness to consider new and different ideas. He was particularly interested in helping his fellow teachers; and consistently expressed the need for better support to drive positive change. He was proficient at classroom management and constantly and consistently encouraged students to think for themselves. Despite his progressive stance, of the three teachers, Wilson had the least experience in an argument-based inquiry approach and, in turn, tended to intervene more with students' argumentation than did Steve and Janet. Also, because his science class was relatively short (30 minutes), he sometimes directed or led classroom discussion to make progress more quickly. Therefore, compared to Steve and Janet's, Wilson's lessons can be characterized as relatively less student-centered and more teacher-guided. Still, in general, his lessons retained many important features of a student-centered classroom.

Part 1.

Essential Elements of Epistemic Orientation toward Teaching Science

The data sources used for the analysis in determining the essential beliefs of EOTS are the transcripts and field notes drafted through two formal interviews and several informal interviews. Data analysis revealed 11 distinct yet interrelated EOTS elements that the three teachers firmly held in common as shown Table 12.

Through this cross-case analysis, it was demonstrated that all teachers had quite strong and sophisticated beliefs regarding knowing, learning, and teaching, and were explicitly aware of their beliefs. In general, the teachers in this study had evaluativist epistemologies that emphasized use of evidence, evaluation of knowledge based on multiple sources (both internal and external sources), and construction of evidence-based argument. Importantly, they did not have domain (science)-specific ideas regarding the nature of knowledge and knowing and tended to apply domain-general approach in instruction. In addition, their beliefs about learning and teaching were quite aligned with a constructivist view which argues that students generate knowledge and meaning by themselves through an interaction (negotiation) between their ideas and other sources of knowledge.

In-depth descriptions regarding these essential beliefs will be discussed in the following sections. The first describes the essential beliefs that all three teachers held in regard to the nature of knowledge and knowing in general, the nature of knowledge and knowing in science, the nature of learning, and the nature of teaching. The second describes how these essential beliefs are related to each other. The third describes how these beliefs were deepened over the course of their career.

Table 12. Comparison between Theoretical and Empirical Dimensions of the EOTS

Dimension	Sub-dimension	
	From Literature (17)	From Three Teachers' Cases (11)
Epistemological Beliefs in general	• Changeability of Knowledge • Structure of Knowledge • Source of Knowledge; • Justification of knowing	• Changeability of Knowledge • Source of Knowledge • Justification of Knowing
Epistemological Beliefs in science	• Open to Revision • Order and Consistency • A Way of Knowing • Use a Variety of Methods • Empirical Evidence • Scientific Models, Laws, Mechanisms, and Theories • Human Endeavor • Questions About the Natural and Material World	• Open to Revision • Questions & Evidence-based Argument • Empirical Evidence
Beliefs about Learning	• Ability to learn • How to Learn (learning procedure)	• Ability to learn • How to learn • Control of Learning
Beliefs about Teaching	• Role of Teacher • How to Teach (Teaching procedure) • Goal of Teaching	• Role of Teacher • How to Teach

Epistemic Beliefs in General

To examine essential beliefs, the three teachers shared regarding the nature of knowledge and nature of knowing, they were asked about four different aspects considered to be the core dimensions of personal epistemology: 1) the changeability of knowledge, 2) the structure of knowledge, 3) the source of knowledge and 4) the justification of knowing.

Changeability of Knowledge.

The beliefs regarding changeability of knowledge was fundamentally similar between the three teachers. All strongly agreed knowledge changes over time, and does so regardless of discipline. All three teachers mentioned *evidence* when explaining changing knowledge and explained the meaning of *change* with an emphasis on the existing knowledge *evolving* rather than merely a new fact being exchanged. They believed that knowledge is constantly re-evaluated based on new evidence. If we look into the thoughts of each teacher more closely, Steve believed that knowledge continually *changes* and *evolves* with time. Regarding the thought of whether one can reach 'one correct answer' or 'one universal truth', with the example of science, he said that rather than ultimately reaching one answer, we look for the more scientifically correct or acceptable answer, through *evidence*. Of course in mathematic problem solving, one answer may exist, yet ultimately, he believed that all knowledge had the nature of changing and evolving.

Like Steve, Janet said that what we know can always change if we gain more evidence and showed strong belief in the tentativeness of knowledge. Janet did not use the word, evolve, but shared with Steve the idea that knowledge *evolves*. She explained that change happens in how we connect the things we already know. Interestingly, she provided examples of how students learn in class to explain that knowledge can be revised in light of new evidence. She stated,

> I know my 5th graders, even today, were completely certain that gravity pulled everything the same. And they tried to drop pop bottles, a full one and an empty one, and they never, they could never get them to hit the floor at the same time. So they weren't sure, 'are we wrong? Should one of them have hit first? Or is what we're doing, are we just not, it's what we're doing wrong—is the tests we're running wrong?' And so, it took a lot of books and a lot of kids trying to put what that was in their own words and a lot of pictures all over the board. Steve even came in and had some conversation with them to ask a different, you know, to ask it from a different way or to bring a different perspective and finally they agreed that objects are gonna, you know, right now we can agree if they're the same mass and the same size they should fall at the same rate but because we're human we can't, we couldn't physically drop them at exactly the same time. So, that's what they determined was the problems I think the more information you, you have as we gain more things, we can reconstruct what we believe about things (Janet, 1st formal interview).

In her view, the changeability of knowledge is reflected in how students learn science in class. She presumed that knowledge changes based on new evidence, because her students changed their understanding of gravity based on new information. This implies that her beliefs about the nature of knowledge is closely linked to or embedded in her beliefs about student learning.

Wilson also strongly agreed that knowledge changes over time. He emphasized that changes in sources, in particular, ultimately led to changes in knowledge. Hence, when considering new evidence, multiple sources must be consulted and compared simultaneously; and the new evidence aligned with the accepted knowledge. He explained that because sources rapidly change and diversify, knowledge should be expected to change constantly. From his perspective, the changeable nature of knowledge is more obvious now than in the past, especially when considering the Internet as a source of knowledge. In other words, in the past, opportunities for accessing multiple sources were limited, which often led to mere memorization than independent verification of evidence on one's own. In the present environment, however, where varied sources are easily accessible, demands are placed on developing the thinking and justification process. Through his account, it is likely that Wilson's thoughts regarding the changeability of knowledge are based on personal experience and reflection. Moreover, as in the case of Janet, Wilson emphasized the nature of knowledge as heavily reflecting how students learn.

Structure of Knowledge.

Among the three teachers, their beliefs about the structure of knowledge were quite dissimilar. In Steve's perspective, the best knowledge can be either simple or complex, depending on the circumstances. He explained his ideas by providing an example from his classroom:

> I guess I have a hard time saying they have to be simple or complex. It could be either one based on the situation. Um, I guess what I think about a claims in evidence for example with the students is something I would use to support. Students are often finding the claim being the initial idea is relatively simple, but all of the evidence makes it complex. So even though the statement, the claim, is simple, the complexity is

much more than what you see in a simple statement. I think it is hard to separate simple and complex (Steve, 1st formal interview)

Steve indicated that while initial knowledge is relatively simple, complexity increases with accumulation of diverse evidence. Considering this development of knowledge, he believed that simple and complex cannot be separated; and all knowledge is inherently connected. Moreover, he believed that this is not only limited to science but can be comprehensively applied to knowledge in general.

On the other hand, Janet asserted that if the best knowledge is too complex to comprehend, it cannot be the best knowledge. Meanwhile, she does not want the knowledge of her students to become excessively simple and thus positioned herself in the middle. According to her, it is problematic if knowledge is so simple that crucial points are left out; nevertheless, if it is too complex to comprehend, it cannot be accepted as the best knowledge. Thus, knowledge can become the best when it is complex only to the extent that it can still be understood. This shows that while Steve's beliefs are concentrated on the knowledge-development process, Janet's beliefs are focused on knowledge as an outcome.

In Wilson's case, he agreed that the best knowledge is basically complex but it is crucial for us, in particular for students, to be able to make it simple. Students must comprehend the simple big idea when learning science, and to comprehend it they must understand that numerous complex ideas can eventually fit into a simple overarching big idea. As a result, in the learning process, comprehending how complex ideas form relationships with a simple big idea should be prioritized.

Wilson ultimately believed that knowledge is not one sided, as it simultaneously exhibits both simple and complex characteristics.

Source of Knowledge.

The three teachers highlighted the process of self-constructing knowledge from multiple sources. In their views, primary sources of knowledge can be diverse, but one can only advance their own understanding when what is known makes sense to them. In particular, Steve and Janet said that *social interaction* plays a crucial role. Steve acknowledged that by negotiating the meaning of an idea with other people alters one's own understanding. He illustrated this by offering an example of his past experience where he developed his thoughts regarding learning and teaching through the interaction with our research team.

> I guess would it be the same in all subjects but it's, it comes from, it can come from textbooks so if things that I am encountering that don't make sense and I'm figuring out with the expert resources. It can come *from my peers*, I know a lot of times in our PD when our fifth grade team sits down we're negotiating together what we believe, just about learning and it continues to change *from our conversation*. It also comes *from just my interactions daily*. So, what I believe about teaching and learning has been *challenged with* Bill [a PD leader] challenging me but I also take it back to my classroom and I *test* it out with the class and say, is this actually true or not? And that is what I'm also believing. So it's really all of them working together, it's not just one higher authority saying this is what you should believe (Steve, 1st formal interview).

As seen in this excerpt, Steve highlighted that knowledge is not derived from one higher authority, but is self-constructed by evaluating multiple sources of evidence, such as information from social interaction, reading, and researching.

Interestingly, he considered both objective sources (e.g. testing and observation of the world; listening to experts) and subjective sources (e.g. personal experience; informal conversation with peers) when he evaluated knowledge. Thus, it seems reasonable to conclude that he has a strong evaluativist view.

Similarly, Janet believed knowledge development to be a *self-construction* process that occurred mainly through *social interaction*. On more specific terms, Janet suggested it was more effective for her to develop knowledge by discussing the meaning of an idea rather than think on her own by reading. Accordingly, considering her own knowledge-development process, she asserted that social interaction played a pivotal role. Although she emphasized social interaction in the knowledge-construction process, she also valued objective sources, such as expert consultation and testing.

Wilson also asserted that knowledge fundamentally comes from self-construction, not from a higher authority. Whereas Wilson did not explicitly emphasize the aspect of social endeavor in knowledge construction, he often mentioned that conversations with others is a valid source of information. He illustrated his beliefs by describing his experience as a sports coach. While coaching, even if he gave numerous suggestions and tips to the players, the players eventually embraced tips that were meaningful to them. In the same context, even if he conveys new and original ideas to the students, they would carry on with their initial ideas unless new ideas were made meaningful to them. He also pointed out that since teachers cannot force students to change their thoughts, the self-construction process should be a fundamental focus in the classroom. He also presumed that it is important for students to have interests or wishes if they are to be engaged in a self-learning process. Namely, he believed students must be motivated to learn something.

To explore teacher beliefs regarding the source of knowledge, the teachers were asked how they viewed authority. As already mentioned above, three teachers shared similar beliefs regarding experts such as scientists or authorities such as a textbook. In their views, these authorities or experts are not higher authorities; and it is essential to compare information with one's own thoughts and ask questions about it.

Steve explained that expert consulting provided a source to reconsider his own understanding. Similarly, a textbook can be considered as an important source; however, he emphasized that he still reserved the right to question. He believed that arguments from experts and textbooks are particularly reliable because they were developed by experienced professionals. Nevertheless, it is still important to compare the arguments with their own ideas and reflect on the idea once again. He asserted that changing the idea or not is his own decision to make, but it is crucial to *cross-reference* with multiple expert sources.

In the case of Janet, although she believed most information from textbooks and experts is *accurate*, people should challenge ideas and reconsider them. In particular, in this procedure, implementing *validation* process through not only one source but through multiple sources is important. She presumes that common ideas suggested by comparing diverse sources are the ideas that many people accept in the present. Wilson also placed importance on *re-analyzing* and *questioning* authority such as textbooks and scientists. He said,

> For the most part we try and look at books and we try to look at information and we do "Brain Pop." And that's good but occasionally they'll have things in there and we'll say, "Hmm, do you agree with that or do you disagree and why?" So there's—it's information but they still have to analyze it. That's where I think we're getting into a little bit of a deeper skill. They're analyzing and synthesizing information. Before, it was: there was no analyst, no analyzing stuff, and no synthesizing stuff. It was all memorization. This is a gospel truth. You learn it. You'll pass the test (Wilson, 1st formal interview).

Thus, he believed that these sources are one type of information, and we must analyze that information once again. Without going through this analyzing and synthesizing information process, it is no more than memorization, and contemplating and analyzing the information oneself brings a more in-depth thinking process.

Justification of Knowing.

Regarding the problem of how to justify what one knows, Steve said evidence is the core of the justification process; and this evidence is produced by the reasoning and data that one has collected. He asserted,

> I justify my knowledge … would be based off of, I guess, all of my evidence, my reasoning, and the data, which is my evidence put together. So, um, making connections between what I've experienced, what the experts say, um, my prior knowledge coming into the idea. Could be the investigations that we're running—it's all of the connections made to support the idea (Steve, 1st formal interview).

In his view, the process of applying evidence drawn from multiple sources to support thoughts is the core of the justification process. Janet also demonstrated a similar idea: by generating and comparing evidence from multiple sources, one can clearly acknowledge what they know and which ideas are better than others. Similarly, Wilson underlines that this is a problem of "how everything fits together." He exemplifies this idea by illustrating a concern regarding the theory of evolution that arose when he taught a unit on the solar system. One can have many different thoughts on unsettled theories, but eventually the procedure in thinking how different theories can fit with personal ideas is the justification process where evidence plays a crucial role.

Summing up, these three teachers were confident that fundamental knowledge changes, and that evidence (or sources) serve a crucial role in this changing or revising process. In other words, the teachers shared the idea that changeability of knowledge is a natural a matter of course. Nevertheless, they demonstrated a fairly neutral position rather than leaning to one side by stating that the structure of knowledge can depend on circumstances or fundamentally carry both characteristics. Although each teacher showed differences in beliefs, there was one common point: all associated the knowledge development process with the learning process. It can be inferred that since the teachers frequently used their students when giving examples of the learning process, they must fundamentally believe that knowledge development is well aligned with the learning process. Thus, it can be assumed that, in these teachers' beliefs systems, beliefs regarding the nature of knowledge and beliefs regarding the learning procedure are well aligned.

On the other hand, all teachers shared the belief that one develops their own knowledge in a self-constructed process of comparing multiple sources and evidence. Importantly, these beliefs effectively reflect how each teacher comes to know something and how students learn. They also asserted that it is essential to integrate new information with their own understanding and contemplate once again whether the sources from scientists or textbooks are credible. This, in turn, is the core of a process that tests the whether an understanding one holds is more valid than the others.

Epistemological Beliefs in Science

Data analysis revealed that the teachers held shared epistemological beliefs in science in three aspects: 1) science is open to revision in light of new evidence; 2) scientific knowledge advances through asking questions and developing evidence-based arguments; and 3) scientific evidence can be developed through evaluating multiple sources that are generated by various methods. Each teacher presented different thoughts and beliefs regarding other aspects of the nature of science, yet they shared beliefs on these three aspects.

Open to Revision.

To begin with, the first belief they shared was that science continuously evolves over time. Notably, they believed that evidence plays a crucial role in change. Steve defined that science is an understanding in regard to what happens and why it happens. However, he emphasized that it cannot be proven that one certain answer exists. What we do is to develop an understanding that is stronger and more acceptable. By providing 'gravity' as an example, he said that we can improve our understanding of gravity but cannot perfectly prove it. He clarified that the meaning that scientists are searching for truth is the truth of the present, not an unchangeable truth. He said,

> So, what I think about what I know is my truth. So scientists searching, I'm searching for my truths, what would be true for me to say. So I a hundred percent believe in what I'm saying, but I also recognize that it might change. Meaning, you know, the 'what is motion?' Initially the kids hundred percent believed motion means movement but when we consulted experts and we had different pieces of data to, to negotiate through, their belief then shifted and changed and it's now what they hundred percent believe until something else doesn't match. Their truth, for now. See we did the clarifier, true for now (Steve, 2nd formal interview).

As he stated above, he clearly believes scientific knowledge can change over time. Besides, as we do, he made a link between the nature of knowing, the nature of science, and how students learn when explaining the nature of science. Supposedly, these different beliefs are interconnected with one another in his belief system.

Meanwhile, Janet said that science is an "exploration of the things around us." She believed that, in regard to the things happening around us, solving and searching for why things take place and how they come to be is science. In this regard, the process in which scientific knowledge *evolves* is fundamentally similar to other fields, except in the case of mathematics where more certain answers exist. In science, different aspects can be explored by focusing more on the process in which a phenomenon takes place and the reason behind it. Furthermore, she said that she was unsure whether science is knowledge, and in her view, science is a way or a thinking process to develop knowledge, not knowledge itself. On one hand, she believed that scientific knowledge is vulnerable to change just like other knowledge. Scientists more often look for answer to questions, rather than seek the truth, and by gaining information science can change. She explained that this change can be a gradual process, where the existing theory changes, or a revolutionary change brought on by a new theory.

Similarly, Wilson stated that science can be defined as an investigation. Explaining that investigation concerning what one has interests and curious about is actually science, he offered an example of his students. His students are satisfied in studying science because one can research their own questions. In contrast, they easily find mathematics a more tedious subject since they are forced to sit still while solving questions with set answers. Furthermore, science constantly faces change, which makes it more meaningful and interesting to study. He explained that the most representative example is the theory of evolution, and added that many scientific theories still are controversial and have ample opportunities to change. Furthermore, new evidence plays a fundamental role in those changes.

Evidence-based Argument.

Another common belief shared by teachers concerning science was that science asks questions about natural phenomenon and scientific knowledge is developed through evidence-based argument. All three teachers acknowledged that science is a process of constructing answers to questions of specific events, and due to that it is crucial to develop arguments in regard to the question. Janet described scientific argument as follows:

> I think scientific argument is being able to express your agreement or disagreement with something based on information that you have, that you would (I suppose) know to be true or can support with other examples. So, it's not just "I don't like you, so I don't agree with what you're saying." It's "I don't agree with what you're saying because I have all of this *evidence* that says something else. It' doesn't match with what I know to be true or what I have examples of in my own life." And I agree or disagree with that based on *that* not based on whether or not I like you or whether or not you're the smart person in the class. Or, whatever my opinion is of you. Or, I don't like the source you found it in. Or, it's *wider* than that. There are *multiple* forms of that out there that I can go find (Janet, 3rd formal interview).

In this excerpt, Janet highlighted that scientific argument must be supported by *evidence*. In her view, evidence solidifies knowledge and builds and argument for consensus on a particular idea. Discussing the difference between opinion and argument, Steve also explained that evidence serves an important role in forming an argument and the "most believable evidence is the one that is the truth that we're currently believing" (Steve, 2nd formal interview). In short, if no evidence exists to scientifically explain the reasons for a particular event, then it would remain merely an opinion. Likewise, Wilson firmly believed that scientific knowledge is developed through generating evidence-based claims; and the evidence comes from several sources, such as some background knowledge we already had, data gathered through investigation, and other knowledge developed by other people.

Empirical Evidence.

The three teachers had coinciding beliefs pertaining to empirical evidence in developing knowledge. They mentioned that evidence plays a significant role in the development of scientific ideas, and thereby it is important to develop multiple lines of evidence using various methods. Specifically, Janet discussed circumstance that promoted learning: rather than simply reading and discussing the textbook, students should learn to formulate their own questions about natural phenomenon and try designing an experiment to answers to their questions. Although she emphasized that this evidence-based approach is not limited to experimentation, she said the comprehensive process of collecting data through research, discussing it with other people, and testing it with experiments teaches students how to build an evidence-based argument. Wilson also emphasized empirical evidence generated by multiple sources. In the excerpt below, he explained why he believed experimentation is important in science.

> We're at a point where you can read and you can memorize that information. But again, it goes back to the truth. How do you know it's true? How do you know it is? Just because the book says so doesn't make it so. Just because the site says so doesn't make it so. If you do some type of experiment and does it line up with the book is saying, then you've got two sources or you've got two things: you've got experience and someone else's knowledge (Wilson, 2nd formal interview).

In Wilson's view, it is important to find patterns across multiple sources and generate multiple lines of evidence to support any single claim. Notably, he assumed that this nature is primarily the same for development of other types of knowledge as well. That is to say, he believed that knowledge is developed and advanced in the same way, regardless of the discipline.

In sum, all three teachers believed that scientific knowledge changes over time, when new evidence comes to light; and it is advanced through evidence-based argument. They also believed that finding patterns in multiple lines of evidence is central to the development of scientific knowledge. Although they described the nature of the development of knowledge in the context of science, hey all acknowledged that believed the same to be true for knowledge in general.

Beliefs about Learning

This section describes the three teachers' beliefs about learning. Data analysis indicated that the teachers held firm beliefs about the Ability to Learn and How to Learn. In addition, beliefs about Control of Learning emerged through the analysis.

Ability to Learn.

In regard to the question of where the learning ability of the students came from, teachers presented different thoughts. First, Steve believed that even if the students are taught the same way, each of them may construct knowledge in different ways. Also, although students' learning outcome varied, depending on their innate ability and different level of effort, Steve believed innate ability only minimally impacts knowledge construction because the endeavor itself drives the learning outcome. Thus, he presumes that a constellation of factors determines learning ability, with effort as the essential source. The most important part he emphasized was that every student has the ability to construct knowledge, and that they can reach a certain level with diligent effort. Certainly students who put in more effort can achieve more, but his mission is for all his students to at least grab the big idea.

On the other hand, Janet accounted that in her case, the study method and strategy largely changes the learning result. By illustrating herself as an example, she feels more effective in learning when she learns by interacting with other people compared to reading a text by herself. She asserted that since people are not born with knowledge, innate ability does not largely influence the knowledge-construction process. She presumed that unless a person is cognitively impaired, effort will guide them in finding the best fitting method. In that sense, in the student-learning process, comparing ideas and striving to think plays a fundamental role. In short, Janet believed that every student has the ability to construct their own ideas and though complexity in outcome may vary, everyone can understand the big idea to a certain extent. For that reason, she repeatedly highlights the need to provide an optimal environment to reinforce this process, which in turn demonstrates faith in students' abilities influences how students are taught.

In Wilson's perspective, effort is the most critical factor in influencing the ability to learn. Though innate ability can be helpful in having confidence, it does not function as the core part. Everyone possesses the ability to think and question ideas. He explained his beliefs by giving an example of his student who is in special education program.

> Just the other day, when we were talking about science with the solar system, I've got a student who's in Special Ed, and I said—I posed the question: one of the ideas was the sun's made of hydrogen and helium and there was an explosion that makes it glow or burn. I said, "Well, do you think we could create a small star on earth? If we've got hydrogen and helium, could we do that?" And we went around and talked and we got towards the end, and his comment was, "Well, we could but the gas will burn out, and we'd be done!" He was the only one who made the comment. Everybody else said, "Yes, the star will burn for a long time," not knowing that the sun is an enormous sphere of gas that is burning constantly. But he had that presence to say, "Yes, that probably would not be possible." Everybody else said, "Yes, that could happen." They were giving different reasons but for him, his was the most valid. I could see that (Wilson, 2nd formal interview)

Wilson asserted that if students are motivated and the teacher provides a little help by asking the appropriate questions, all students can think and construct their own meaning about a concept. Although they may be endowed with little innate ability, he said they can fully overcome this through effort. While the three teachers held different views on the factors that impact ability, they agreed all students have the potential to form knowledge themselves. Accordingly, they emphasized the importance of providing ample opportunities for students to speak their ideas, raise questions, and construct meaning on their own. This finding revealed that the teachers' beliefs about student ability are closely related to their beliefs about how to teach.

How to Learn.

Steve believed that learning is a process, a way of experiencing certain phenomenon, negotiating what you already know, and integrating evidence from multiple sources with your own ideas. He stressed that knowledge construction is initiated by the process of students discussing their own claims and having a critique. Steve described how his students learn by illustrating the process as is happened during their study unit on 'Force and Motion' with details. To speak in Steve's context, the first stage is to think about what the students already know about 'Force and Motion' and have a discussion. To address the questions raised in the first stage, the next stage is to design an investigation using the materials provided. In addition, students actually conduct an investigation and intellectually negotiate interpretation of the results. During the negotiation process, learners compare multiple sources, test results, excerpts from the text, materials discussed, and, importantly, challenge each other's ideas. Through this procedure, Steve asserted, students can arrive at a consensus: this comprehensive process is the learning procedure. He summarized this process as a cycle of negotiating, writing, thinking and talking, and that this cycle is basically applied similarly in all other topics. He presumes learning is a negotiation progress; and the core of his beliefs is that through negotiation students can reconstruct a conceptual framework with the new information. This idea is nearly consistent with his beliefs about the nature of knowing. Furthermore, through this negotiation progress, he believed students can reach consensus most of the time, but in other cases students can conclude that two possible answers might hold true, which in turn emphasizes the importance of the negotiation procedure. Another interesting fact is that he believed students construct knowledge in the same manner as his own, and that learning process is fundamentally the same regardless of the discipline. In other words, in his belief system, beliefs about the process of knowing and beliefs about learning are intimately correlated and well aligned.

Janet exhibited similar ideas, and described that first step in learning as thinking about and discussing what an individual already knows. In her view, this step is crucial because it lays out the existing framework to which the new information must connect. The following excerpt shows Janet's beliefs about how students learn.

> I think they have to maybe have an opportunity to think about it and talk about it—a lot of kids will just say 'I don't know anything about that' but when they get time to think about it they may have pieces that they can connect to it at this point so I think they have to come to some sort of idea about what they think they know about or what they know about it right now. And then start to wrestle with whether that matches what they're hearing from others, what they're reading, what's happening with an experiment or you know, just what's happening around them. Does, does that continue to match? And, if it does match, are there pieces of what's going on that I can add to it to make it stronger? Or are there pieces that don't match and am I willing to change those, because sometimes we, our pride gets in the way of being willing to change—that I'm supposed to be right so I'm just going to stay with what I have even though it might not be what's matching or can I take pieces of what I see and change the pieces that don't fit (Janet, 1st formal interview).

Janet believed that through the process of sharing opinions, students compare what they have heard, read, and observed through experiments. Furthermore, she highlighted that students determine by themselves whether they should change their ideas, add an idea, or carry on with the existing thoughts and thus, it is during this process that learning takes place. She summarized student learning as a process in which one's own ideas are continuously negotiated.

Wilson voiced beliefs that were fundamentally similar: that students should construct their knowledge by themselves. He focused on discussing students' existing thoughts and information gathered from multiple sources and how these ideas can be tied together. At this moment, because the students assume the role of an 'investigator', coming up with differentiated ideas through experiments and research, it is essential for them to take an interest in the subject. He mentioned that if students cannot arrive at a consensus, he helps them see how the ideas are connected. However, it cannot be helped if they adhere to their idea, and thus highlights that the main agent in learning is the student. He also presumed that although the learning processes share common factors according to discipline, as in the case of mathematics problem solving takes a major part.

Control of Learning.

One notable aspect found in each teacher's beliefs about learning was that all three teachers weighed in heavily on 'control' issues between students and teachers. The point is who the subject is in leading the learning process. Regarding this idea, all three teachers held very strong beliefs that students are in control of their own learning. During the interviews, they repeatedly emphasized that this idea played a critical role in shift their orientation from teacher-centered to student-centered. This is illustrated in the following excerpt.

> What I have heard and at least what I know is most important to me was the whole, what is teaching and what is learning? Because that's one conversation, no matter what I'm doing in my class, keeps coming back. So the moment when I might start getting on my high horse and preaching to the kids, you know it comes back to I start watching them,

> they're disengaging, they're thinking about other things, I have no control over what's going on right now, why am I doing this, it's a waste of my time. So, I think that's, even though it's really uncomfortable, it's really needed to really dig down into the core of your belief, this is my job it's teaching and learning. (Steve, 3rd formal interview)

As Steve highlighted, his whole belief about teaching and learning had to be restructured since he was challenged by the idea that he, as a teacher, had no control over what was going on in students' mind. As he believed that students are in control of their learning, students' came to be the agents in each step of the knowledge-construction process: they generate questions, think about their own ideas, and generate evidence to support their claims. He also asserted that a comprehensive process of classroom negotiation should be entirely determined by the students. While reflecting on his teaching, he consciously acknowledged this control issue. Thus, it seems to be evident that his belief about control of learning is a key tenet that greatly determines how he actually creates a learning environment in the classroom.

Janet also believed that students should bear "ownership" in every facet of learning. She said, "That is learning itself", adding the comments that students should be engaged in the comprehensive process of generating questions and constructing answers, by holding ownership of their ideas. Janet believed that she had to empower the students by giving opportunities to decide the focus and sequence of the classes for themselves. In her view, students must go through the process by themselves to come to know, and teachers' help should only be provided to the extent that this aspect is not undermined. With this idea in mind, she situated herself as a middleman who provided resources for student knowledge construction. As shown in Steve's case, Janet's belief about control of learning is highly associated with her beliefs about role of teacher and how to teach.

Likewise, Wilson held a firm belief that teachers cannot control students. According to him, this strong belief has been greatly influenced by his personal experience, chats with other teachers about learning, and lastly his own learning through the SWH PDs. He explained as follows:

> Part of the thing that Bill [a PD leader] was talking about is, do we control their learning? The answer is no. It's the kids. They control their own learning. I took that a step further. We have kids that have behavior problems. Do we control their behavior? No. They control their own behavior? We try to make them do this and this and this, but they're in control. That's what we have to, we have to keep looking at is how can we help them make good decisions when you're talking about behavior. Because they're in control. (Wilson, 2nd formal interview)

Even with quality information, knowledge is meaningless unless the learners think for themselves and build their own understanding, he believed. Importantly, he felt sure that this change in thought significantly impacted his own teaching approach. As he described in a formal interview, before he built this idea, his teaching was very teacher-centered and centered on memorization of factual knowledge. However, since he came to believe this idea, he demanded that his students be engaged in the thinking process.

In all three teachers' cases, beliefs about the control of learning appeared to have a strong effect on their beliefs about teaching. Although this belief was not addressed in the theoretical framework of this study, it seems reasonable to assert that this should be included in the belief set for the EOTS.

To sum up, while three teachers demonstrated small differences in opinion concerning learner ability, they agreed that all students are equipped with sufficient ability to construct their knowledge. They agreed that although learning outcome may vary due to different levels of ability and effort applied, if all students are engaged in learning, they can achieve a certain level outcome. This is largely significant because it demonstrates how teachers can offer opportunities to their students. On the other hand, the teachers all had constructivist idea regarding how students learn. That is, they agreed that learning is a knowledge construction procedure in which students connect new information to existing ideas. They agreed that students participate in an iterative process in which they can elicit their opinions and negotiate ideas learned from variety of sources, and this is the knowledge construction process is where students contemplate how different sources may be connected. Noticeably, the teachers' beliefs about how students learn accurately coincided with their beliefs about knowing; and all three did not view the knowing process and learning process as separate. Namely, this implies that, for these teachers, beliefs about knowing and beliefs about how students learn are closely linked and well aligned. Lastly, each teacher placed import in students as the subject in learning and that students should make the connection between each idea through negotiation. Specifically, the belief that students are the agent in learning greatly affected how the teachers created learning environments for students.

Beliefs about Teaching

This section describes the teachers' beliefs about teaching. While the teachers had similar beliefs regarding their roles and how to teach science, they had different levels of goals for teaching. The analysis indicated that their goals should be considered the learning expectations they set up for their students rather than their beliefs that shaped their instructions.

Role of Teacher.

Regarding questions concerning the role of the teacher in the learning process, Steve answered that teachers should serve a *management* role. The teachers should separate students into where they can debate freely; they should manage help prevent the group work from dispersing. Moreover, when student discussion is suspended, the teacher should spark conversation through questions—which is more managing the conversation than directing, guiding, and stating ideas. He argued that, in some cases, the teacher can manage learning by providing a concise instructional piece when the students have trouble moving forward.

Janet divided her roles into several parts. The first role is to manage the student decisions while considering the resources. She believed students will decide what to do by themselves in most cases, but by exploiting limited time and limited materials, she can advise whether their plans are feasible. Also, she frequently provides opportunities for students to gather information independently and to do research. Janet defined this role as a resource person. If the students lack adequate information, she said, she would search together with them to provide solutions and ask for advice from other staff members. She also believed it is the role of the teacher to manage classroom ideas, not lead or direct it. She manages by bearing in mind whether student ideas are correlated with the science big ideas or whether they are interconnected with the standards. In particular, Janet demonstrated that she was constantly aware of that she should give maximum ownership to the students in positioning her role in different ways. That is, she can give a hand to students, but the critical process in knowledge construction is making sure that students can participate on their own.

In Wilson's perspective, he defined himself as the facilitator who provides helps to the students when they need it. He elaborated on the role of the facilitator as the following:

> Facilitator is: you're there—you're there to guide and direct. Give them some direction on maybe how to set up an experiment or how to go about answering a question or having them bounce some ideas off you. I see myself all the time, now—I'm going around the room and I'm just seeing what they're doing. I might give them a few suggestions here and there if they ask. But I'm letting them try to get them to figure it out by themselves (Wilson, 1st interview).

He asserted he changed his beliefs in regard to his own learning, and then his belief concerning the role of the teacher followed suit. He indicated that while he had acted as an expert in class in the past, he now waits for the students to act on their own, and encourages them by asking questions. In addition, he believed that his main role should be managing resources and environment. In sum, his ideas fairly well paralleled those of Steve and Janet.

How to Teach.

According to data analysis, the beliefs on teaching can be divided into two large sectors. Above all, how the teachers create a learning environment is the first. The second is how the teachers should help overcome learning difficulties through interaction with the students. First, all the teachers emphasized the importance of the student ownership in regard to forming a learning environment. This belief is associated with the teachers' beliefs about the control of learning. As mentioned above, the teachers said that formulating an environment that can urge the students to participate in their own thinking process plays an important role. The first step is to give opportunities for students to think about their existing ideas. The second is to openly discuss their ideas with others and take the time to reconsider their ideas after listening to others' opinions. The third is by comparing the multiple sources drawn from experiments, reading, researching, and listening to other people's ideas, one can create an environment where students can contemplate how the new information fits with their own opinion and what supports the idea or what should be changed. These beliefs align well with the ideas on how students learn. In short, they do not focus on what they should do in teaching but are always placing priority on what conditions are needed to foster student learning.

Similarly, their beliefs about learning are well reflected in how teachers interact with students and provide help in situations where students face difficulty in understanding a particular concept. They said that providing more time when students are faced with a difficulty is key; and asking questions actively can give them a hand as they construct their thinking roadmap. For instance, Steve perceived the importance of negotiation in regard to thoughts students have in mind; his thoughts are thoroughly implied in the interview quote below.

> Through the negotiation of why they thought things happened. So getting the students to predict what they thought would happened, we run a simple investigation, and then from that they had to say why it was happening. They had to negotiate through it. So, that was for me that's a really fun one because the bottles hit the ground at the same time and yet the students are so stuck in their idea, they'll still say, "They hit differently." We'll look at the video and they'll see the bottle hitting at the same time but "No, they hit way different!" What they want it to be shapes what they think rather than what they actually see. So, getting them to say, "I've got to recognize what I see and then come to terms with it and negotiate though why that's happening." Coming back and saying, "Well, objects are made of mass. Gravity. What's gravity doing? Gravity's pulling our mass." (Steve, 2nd formal interview)

When students have difficulty in dealing with a particular idea, he said that he would jump in the negotiation process and actively help the students by first finding out their thoughts and then assisting the students to make meaningful connections. While he participates in the students' learning process, he stressed that he would not tell or direct the students. Rather, he would give supportive scaffolding by asking thoughtful questions in the negotiation with the students.

Goal for Teaching.

Each teacher had teaching goals that exhibited small differences, and this is relevant to the learning expectations/outcomes of the students. First, Steve mentioned that he wanted his teaching to have impact upon students' learning. Due to the fact that students start from varying positions and possess different characteristics, he said that his position lied in ensuring that as many students as possible grabbed the big idea. In addition, he clarified that he wanted students to experience what science is. He wanted students to think, speak, and experiment like scientists; understand how to make use of data; formulate claims and be engaged in to support these claims using evidence. In each unit, there always is the "must-know" things, and his goal is to help all students develop an understanding of them. In Wilson's case, his goal is to help students appreciate the scientific method and evolve critical thinking skills. Furthermore, he wanted the students to overcome their fear of asking questions and constantly think about the different ideas and develop them further. Clearly, their thoughts had some overlapping points, but the scope and depth in goal varied according to the teachers, and in fact, it is more accurate to say that these beliefs originate from their experience and thoughts, and are more like statements regarding what they hope and expect. In other words, the characteristic is a little different from the beliefs mentioned above.

In essence, it can be surmised that beliefs about teaching are deeply relevant to beliefs about learning and beliefs about knowing. All three of the teachers studied here strongly believed that teachers should provide active help if necessary, but help should be limited to fostering an environment where students make connections by themselves; help did not mean giving away answers or leading the conversation in an arbitrary manner.

Summary

Among 17 theoretical sub-dimensions drawn from the literature, 10 were recognizable as beliefs that the three expert teachers strongly held. In addition to these 10 sub-dimensions, one dimension emerged as critical—this concerned beliefs about who controls learning. Although this seemed to be highly inter-related to the beliefs about how to learn, it was recognized that the perceptions of control led them to change their whole beliefs system. Although the first-level analysis already showed that these 11 belief elements were interrelated and each dimension made at least one connection with the other beliefs, these interrelationships will be discussed further in the next section.

Interrelationships between 11 Essential beliefs

To examine the interrelationship between 11 belief dimensions, the second level analysis focused on detecting connections between two or more dimensions. Through the coding, number and structure of connections were determined. The results were illustrated in Table 13. This table shows the number of connections that each dimension made with others.

This analysis indicated two noticeable similarities across the teachers: 1) Beliefs about How to Learn (L2) was the most frequently connected dimension; and 2) Alignments between beliefs about Source of Knowledge (G2), Evidence-base Argument (S2), How to Learn (L2), and How to Teach (T2) form a core structure of the EOTS.

Table 13. The Results of Coding for Interrelationship

Dimensions	Sub-Dimensions	Code	Steve	Janet	Wilson
Epistemological Beliefs in General	Changeability of K	EG1	6	2	1
	Source of K	EG2	11	8	15
	Justification of K	EG3	4	4	5
Epistemological Beliefs in Science	Open to Revision	ES1	4	1	2
	Evidence-based Argument	ES2	13	12	20
	Empirical Evidence	ES3	4	2	2
Beliefs about Learning	Ability to Learn	L1	1	1	4
	How to Learn	L2	30	21	29
	Control of Learning	L3	2	6	8
Beliefs about Teaching	Role of Teacher	T1	3	2	5
	How to Teach	T2	24	15	25
			102	74	116

First, beliefs about How to Learn (L2) were most frequently connected to other beliefs. In particular, this L2 was often associated with beliefs about how to teach. That is, the teachers considered how students learn when they thought about teaching. Given that teaching is meant to serve learning, this is quite anticipated. Steve clearly stated that belief about how to teach is "coming from what our perception of learning is, negotiation, building the knowledge and our conversations we're having down the hallway of what worked for you, what didn't" (Steve, 1st formal interview). Meanwhile, the L2 was fairly often connected to epistemological beliefs, in particular, to G2. This connection is quite original and important because the relationship between these two beliefs is not well explores. In these teachers' views, the process of knowing is reflected in the process of learning. They believed that their students learn fundamentally in the same way they do. More importantly, this belief was associated with almost all other components, suggesting that the L2 is a core belief that leads or affects other belief dimensions.

Second, LS, T2, G2, and S2 aligned well. In Table 13, these four belief dimensions were the most frequently connected with other beliefs. By closely examining these associations, it was found these beliefs are strongly interconnected. As mentioned earlier, the ideas that underlie in G2, S2, L2, and T2 are all well-aligned in these teachers' beliefs system. The key idea the teachers held regarding G2 was that people must construct knowledge for themselves, through negotiation and multiple lines of evidence/sources. This belief was reflected in their concept of the student learning process (L2) and How to Teach (T2), as well as their beliefs about how scientific knowledge is developed. When describing student learning, they all highlighted that students develop their knowledge through making meaning by themselves, based on multiple sources. Thus, from their perspectives, their teaching should focus on creating a learning environment when students can share ideas, generate evidence to support their claims, and argue.

Development of the Epistemic Orientation toward Teaching Science

Although the focus of this study was to examine beliefs the three teachers held currently, they frequently reflected on how they had changed their beliefs throughout the course of their career. To depict a more complete picture of the EOTS, the comments regarding the change in their beliefs were also analyzed. In this regard, this section will discuss how the teachers developed their current beliefs.

First, questioning their beliefs about learning was the most critical initiator that led them to reconstruct their ideas about learning and teaching. In the excerpt below, Steve stated that having a chance to think about what learning is was very momentous for him, and prompted him to rebuild his concept of teaching and learning.

> When I was sitting in the room and Bill [a PD leader] kept going around saying 'What is learning?' I guess that was, that was really critical because I had never thought about it before and that was our job. We're in a learning profession and yet I had never thought about what learning was. And, we went back to our hotel rooms that night and we went out to eat and we're talking through what is this? Because we've never thought about it before, so we started building it at that time (Steve, 1st formal interview).

As he said, he had never thought about what learning is until he was constantly asked to think about it. It did not merely mean he did not have any knowledge about learning or learning theory, rather it meant that he had never had to dig into his own idea about learning until he got challenged in a PD. Wilson's case was quite similar Steve's. He reflected on a day that he first got questioned about learning. He stated,

> He was constantly barraging us with ideas of: who controls your learning? Who controls their learning? He argued with us back and forth with that type of system—Well, what about this? He posed those questions. Until you change that mindset, you're not going to change. We as a group, we had to fight through that, but then we started realizing, "Yes, there's probably a lot of truth to that and we need to try this" (Wilson, 1st interview).

In his particular, beliefs about who controls learning were the most critical. Before his ideas on these topics were challenged, he said, his teaching was teacher-centered and focused on memorization of the facts. However, since he began to explore the idea of control, he came to realize that he did not control what was going on in students' heads. This idea sparked a change in his beliefs and practice. Janet also asserted that she began to change her idea about learning since she was asked to think about who controls learning. As she developed ideas about the control of learning, she came to believe that students are responsible for their learning and think of "why not give them the opportunity to have ownership?" The change in her beliefs about learning led to the change in her orientation to teaching.

Second, the changes in beliefs about learning enabled the teachers make new connections between their existing beliefs, and in turn they changed their orientation toward teaching science. When they were asked about the origin of their current beliefs about knowledge and knowing, they all claimed that it came from personal experience. Still, their beliefs about learning and teaching evolve based on what they are doing, what they see, and how students work. They asserted that the paradigmatic changes in their beliefs about learning enabled them to see how their existing beliefs could fit together with their new ideas about learning. The teachers did not make any strong connections between how scientific knowledge is developed, how students learn, and how to teach until they were asked to change their beliefs about learning. In the excerpt below, Wilson described how his beliefs about learning impacted on how he taught science.

> My belief about science probably comes from just my past history of being involved in science classes, like when I was in 5th grade, I loved science… Then I just continued as I grew to take more science and science classes and different types of studies with science. So that's how I've got my science background. The only change in the science is the way we *teach* science. We knew how science knowledge is developed. But we didn't apply it…However, after we changed our perception of learning, everything was changed. We had to get into that argument of, well, it could have been different and this and that. We could see how it would work with kids and we started to apply it (Wilson, 2nd interview).

As he said, his beliefs about science and beliefs about learning and teaching were not connected before he changed his idea about learning. Rather, those beliefs existed as separate forms. However, he built connections when he changed his idea about how students learn. He came to realize that his teaching could be different and the nature of science could be reflected in student learning. Janet also stated, "I think I have changed my opinion of the *importance* of the nature of science. And not necessarily what it is, you know, but just how important it is that kids see it and are a part of it". Thus, she also began to make a connection between the nature of science and how students learn after she changed her beliefs about learning, and began to see the importance of nature of science in terms of student learning.

Putting all these findings together, this study developed a conceptual model of EOTS as shown in Figure 6. As depicted in the schematic, the beliefs about learning (in particular, beliefs about how to learn) are placed in a center because these beliefs are associated with all other belief components. As the teachers asserted, the changes in their beliefs about learning led to changes in the whole structure of their beliefs. Therefore, it seems reasonable to argue that beliefs about learning should be placed in the center of their orientation. In addition, the strong alignments between L2, T2, G2, and S2 were also represented in this model. The teachers developed strong epistemic orientations to teaching science by seeking the alignments between how knowledge develops, both general knowledge and science knowledge, and how student learn, and how they should aid student learning in the classroom. Moreover, their change in beliefs about learning prompted them to restructure their concept of effective teaching. This conceptual model outlining these relationships will be built on, based on the evidence generated in Part II and throughout the study.

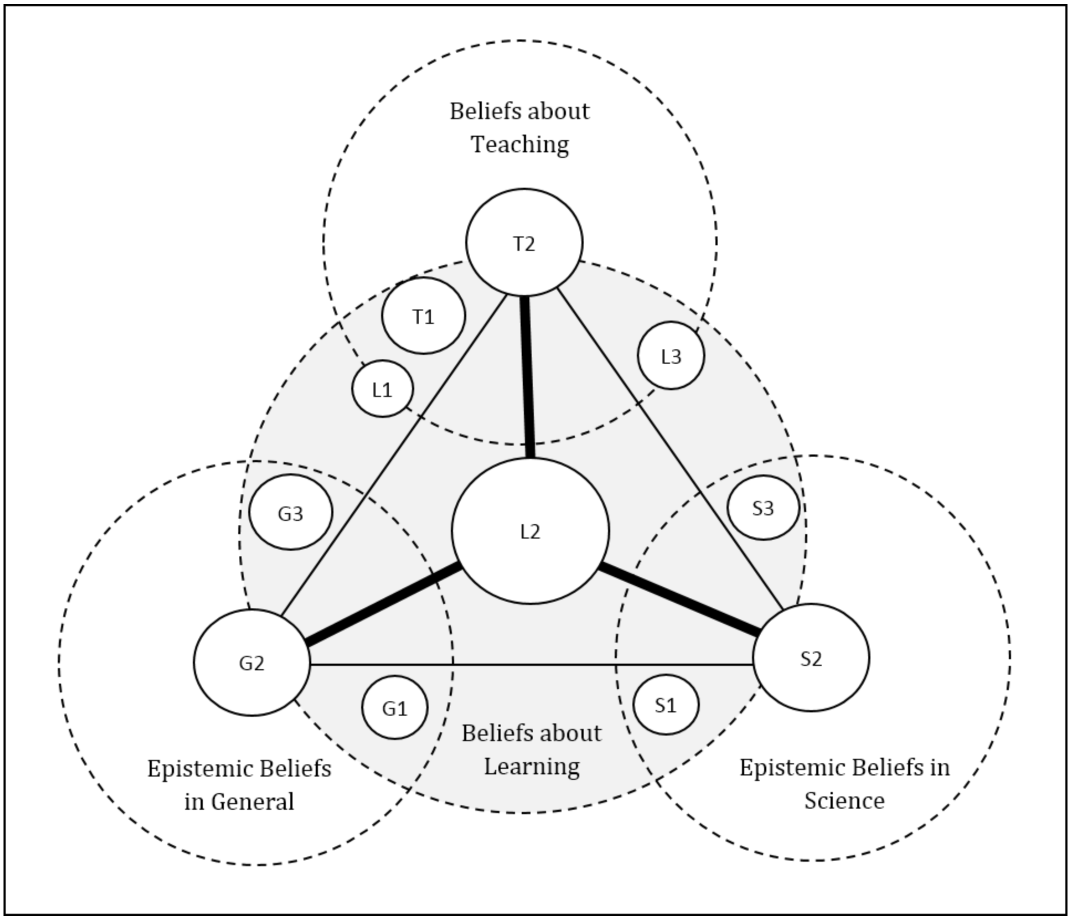

Figure 6. A Conceptual Model of EOTS from Part I analysis

Part II.

The Relationship between Essential Elements of EOTS and Instruction

In part II, the analyses examine the relationships between the essential elements of EOTS and instructional practices of the teachers. The main data sources were video-taped lessons, semi-structured interviews, VSR interviews, classroom artifacts, student notebooks, and field notes. In this study, instructional practices refer to routine activities that teachers engaged in that are devoted to planning, enacting the plan, and interacting with students. In addition, from the theoretical framework of this study, science practice was viewed as integrated practice that encompassed three dimensions: 1) cognitive (conceptual and epistemic), 2) social (language and group), and 3) physical (time and physical material). Although no standards or literature offered a clear guideline for how to integrate the three dimensions to shape a coherent instructional practice, the analysis of data in this study revealed that the cognitive dimension (i.e., the conceptual and epistemic dimension) was the one that drove the direction of instructional practices. On the other hand, language and physical dimensions were used as tools to create learning environments where students could achieve their cognitive goals. With this in mind, the first section describes the essential elements of EOTS that were critically used in the teachers' decision-making processes. Then, the second section describes in detail how these essential beliefs were related to the ways that the three teachers incorporated the three dimensions of practice into their planning, enacting, and interacting, to foster student engagement in science practice.

Essential Elements Used in the Decision-Making Process

The main data sources used in this section were eight video-taped lessons, one semi-structured interview, and one VSR interview for each teacher. During the VSR interviews each teacher was asked to reflect back on their instruction for each lesson and explain their reasoning for the decisions they made during instruction. The Table 14 presents the frequency of each element reflected in their instructional decisions. The analysis found four prominent patterns: 1) Beliefs about How to Learn were the most frequently used when making instructional decisions; 2) the teachers' beliefs about Control of Learning often determined the student-centeredness of instruction; 3) the teachers paid more attention to learning than to teaching; and 4) Ability to Learn, Changeability of Knowledge, and Open to Revision were the dimensions that used the least frequently in the teachers' decision making process.

Table 14. Frequency of the Essential Elements being used in Instructional Decisions for Each Teacher

Essential elements (11)	Steve	Janet	Wilson
1. Changeability of Knowledge	0 (0%)	1 (1%)	1 (1%)
2. Source of Knowing	9 (11%)	10 (10%)	4 (5%)
3. Justification of Knowing	7 (9%)	10 (10%)	6 (7%)
4. Empirical Evidence	7 (9%)	9 (9%)	1 (1%)
5. Evidence-Based Arguments	6 (7%)	7 (7%)	3 (4%)
6. Open to Revision	1 (1%)	3 (3%)	0 (0%)
7. How to Learn	23 (28%)	29 (29%)	27 (32%)
8. Ability to Learn	1 (1%)	0 (0%)	0 (0%)
9. Control of Learning	10 (12%)	11 (11%)	21 (25%)
10. How to Teach	11 (14%)	12 (12%)	9 (11%)
11. Role of Teacher	6 (7%)	7 (7%)	13 (15%)
	81 (100%)	99 (100%)	85 (100%)

First, the results show that the most frequently used element in their instruction concerned Beliefs about How to Learn. The three teachers frequently made connections between the way of teaching and how students learn. For example, in a lesson, Steve was working with his students to discuss the relationship between mass and speed and had his students reflect on their original claims and decide if they wanted to revise their ideas based the discussion they had with each other. In the excerpt below, Steve was reflecting on his instruction for that day.

> The students were reading through their critique[s] and they were deciding what they were going to do with that. Whether it's revising, just completely rewriting, or if we were confused. There was at least one group that was asking for help. They were struggling so I was willing to work with them on that. And as we were working it through, hearing other conversations, I opened it up to the group saying, "anyone else want to join us?" Nobody obviously did. I think one group tagged along. I'm still pretty certain that later on more groups started coming over, but I could be wrong. The purpose was to get the kids to go back and look at when they constructed their knowledge. Were they starting with what they knew, on the prior knowledge, or were they just making leaps, guesses? It was important, I think it's just part of that whole learning piece of, "it's important to build on what you know." So our learning is continually built, it's constructed. It's not just random guesses that we throw out and support. To advance their thinking from here on out we kept using that same language of, "Use what you know. Let's keep building on it" (Steve, VSR, lesson 5).

In this lesson, Steve repeatedly asked his students to think about what they knew and what they added to their prior knowledge. He created a learning environment where students could share ideas and construct meaning together because he believed students learned through private and public negotiation. His students were engaged in their learning processes by interacting with other students, and writing their thoughts in their notebooks and thinking about what they knew. Moreover, this pattern of learning constantly appeared through all his lessons. As he believed that learning is a cycle of negotiation, cyclic patterns were predominantly reflected in his instruction. Thus, it seemed clear that Steve's beliefs about How to Learn shaped the general patterns of his instruction.

Likewise, Janet and Wilson also continuously paid attention to how their students learn. They continually discussed how their students learned throughout the lesson. They seldom paid attention to their teaching itself, but concerned themselves with what their students had been doing and how the students learned through that process. In their classrooms, they provided their students with opportunities to construct ideas and critique each other because they believed their students learn through construction and critique. Accordingly, their beliefs about How to Learn evidently influenced their instructional practices.

Second, another critical element continually considered in their instruction was the teachers' beliefs about Control of Learning. As presented in Part I, all three teachers believed that students were in control of their learning and this was frequently interconnected to their beliefs about How to Teach and Role of Teacher. Indeed, the belief about Control of Learning was often associated with their instructional decisions on how much they would give their students the power/authority to construct knowledge and determine practice. In a lesson, Wilson had been working with his students to discuss experimental variables. In his VSR interview below, he explained why he gave his students a chance to discuss their ideas.

> And the reason I brought up Jeremy's books, Jeremy used the little books, and he had different sizes. Well, do you want to do that? You know, we throw out those different ideas. This is negotiating. This is the thing that, "Okay, you're in control. What do you want to do?" because it's their activity. If it was totally teacher-controlled, I'd say, "Four books. Ramp. Whatever." So I'm letting them kind of dictate or decide, "Well, what do we want?" (Wilson, VSR, lesson #6)

In this excerpt, he asserted that he was trying to give more power/authority to his students because he believed it was the students' learning and they were in control of it. In this lesson, his way of teaching originated in his beliefs about the Control of Learning. Specifically, this belief determined whether his instruction was more student-centered or teacher-centered. Among the three teachers, he relied on his belief about Control of Learning the most frequently when teaching. Sometimes, he reflected that he was more teacher-centered in a particular lesson and would give more ownership to his students the next time. It seemed that he was still adjusting his instruction based on his belief about Control of Learning. While his belief and his instructions were sometimes not perfectly aligned, it was clear he had shifted toward a student-centered approach by adjusting alignment between his beliefs and practices. On the other hand, although Janet and Steve also considered this control issue by repeatedly mentioning "ownership" and "control", their beliefs about Control of Learning were well reflected in their instructions. They continuously adjusted the balance of power/authority between students and teachers throughout the lesson by relying on their beliefs about Control of Learning. In addition, they said most of the instruction related to giving ownership and power to students in a class were not planned or predetermined, rather it was instantly decided based on their students' needs and their beliefs about learning. Although the degree of alignment between beliefs and practices was different between the teachers, in all three teachers' cases, the beliefs about Control of Learning played critical roles in shaping their instructions toward student-centered approach.

Third, as discussed above, the teachers paid more attention to student learning than their own teaching. Table 14 shows that the teachers relied on their beliefs about learning (How to Learn and Control of Learning) more than or equal to

40% of time (Steve: 40%, Janet: 40%, and Wilson: 57%), while using their beliefs about teaching (How to Teach and Role of Teacher) less than 30% (Steve: 21%, Janet: 19%, and Wilson: 26%). When reflecting on their instruction, they rarely paid attention to their actions regarding classroom management. They heavily attended to how much their students were engaged in their learning process and what kinds of help the students might need to improve their learning. Given that teaching is a decision-making process, it is important to understand what thoughts and beliefs were valued most. In the excerpt below, Steve explained how he made decisions between what students needed and what he wanted to do. He explained:

> Knowing that I have power in a conversation, but also recognizing that if that's not where their thought needs to go, it's irrelevant to them and it's not going to make a difference. We can enter a whole-group negotiation and I need to be, I guess, tender with where they're at, and be flexible to say, "This is what I want, not what they need." It's not about me, it's about their learning. I can definitely try to push, I can ask questions, but recognize if that's not where we're at, I need to shift.

He focused on student learning much more than what he, as a teacher, preferred to when making instructional decisions because he believed his job was about student learning. It goes without saying that his strong beliefs about learning led him choose a more learning-focused/student-centered approach.

Janet and Wilson showed similar patterns. They discussed student learning and how they could help their students learn much more than they discussed how they wanted to teach. In an interview, Wilson said that he was not "instructing" anymore. Rather, he said, he was just helping his students engage in their learning process. For these teachers, classroom instruction was not about teaching but about learning.

Fourth, Table 14 shows that Ability to Learn, Changeability of Knowledge and Open to revision were the least frequently used in decision making, despite that the analysis in Part I uncovered that these elements were all interconnected. This does not merely suggest that these elements do not affect teaching, but rather that the teachers did not explicitly consider these elements when making decisions. Changeability of Knowledge and Open to Revision were the elements relevant to the nature of knowledge. These beliefs about knowledge are inherently embedded in or closely interconnected with nature of knowing. Therefore, it seems reasonable to infer that these beliefs are inherently embedded in other beliefs, such as Source of Knowing and Evidence-Based Argument.

Also, Ability to Learn seems to be an underlying belief that affected How to Teach but was not explicitly and separately considered all of the time. In Part I, this belief was clearly distinguishable and closely related to the teachers' beliefs about How to Teach. Thus, it is highly plausible that this belief was embedded in How to Teach when the teachers made decisions, and did not directly affect instructional decision making all of the time. Nevertheless, this inference needs further investigation.

Instructional Decisions in Planning, Enacting, and Interacting

This section describes how the three teachers incorporated cognitive, social and physical dimension of science practice into their instruction. In particular, the results focus on how the teachers made instructional decisions when planning practice, enacting plans, and interacting with students.

Planning decisions.

The planning decisions and considerations of the three teachers were quite similar. The analysis indicated that the teachers predominantly considered *what to teach*, rather than *how to teach*, when planning lessons. All three teachers shared five noticeable patterns of planning: 1) They decided what to teach based on published science standards, but did not explicitly plan how to teach. 2) They set both conceptual and epistemic goals for their students. 3) They roughly designed topic-specific resources, activities, and questions that they would use to help students build an understanding of a particular concept.

Determining what to teach.

The three teachers relied on published curriculums, such as "Iowa Core" or "Next Generation Science Standard (NGSS)", to decide which big-ideas-in-science topic to teach. Although all science topics were driven by these formal science standards, the teachers identified big ideas for the unit during planning. The big ideas are the "must-know" things in a particular unit that the teachers wanted their students to understand well when they left the classroom. The teachers believed that the published curriculums guided them at least to determine what to teach for a specific grade level and on a certain topic. During planning, they determined big ideas by themselves based on the published science standards and usually had conversations with their peers to determine whether the big ideas were plausible and intelligible. After determining big ideas for the unit, they roughly outlined what to teach for each lesson based on their knowledge and experiences of how each science concept should be connected to big ideas and how their students would make these connections. They outlined the science concepts they would likely work on each day, without planning exact timelines for each lesson.

On the other hand, the teachers did not explicitly plan *how* to teach. Steve said, "Timing and how and when it happens is something that typically happens spur of the moment" (Steve, 3rd). Thus, planning how to teach was not the routine they typically had. Indeed, they were not able to prearrange structure of a lesson or how to teach before they went to their classrooms because they believed that the direction of the lesson should be determined by students' ideas and interests. Wilson asserted,

> Like I said, the thing that is hardest about the student-centered approach is you can't plan. You can only plan a day ahead and then when that day gets here, then you see what happens and you, depending on what happened that day, you plan for the next day. You have an idea of what's going to happen the next day, and but during that time, you don't know for sure if you, what you're going to do is going to work. You just have to be flexible (Wilson, 3rd interview).

As Wilson explained, student-centered instruction was built around students' prior knowledge and their own questions about the topic. Hence, lessons cannot be prescribed by teachers before they find what students know. Moreover, whereas the published standards guided them to determine what to teach, the teachers pointed out that the science standards did not provide any guidance of how to teach. According to them, they decided how to teach based on their beliefs about learning. Instead of planning a particular structure for every lesson, they applied topic-general and student-centered approaches which were shaped by their beliefs about learning. Constantly creating a space for students to share, negotiate and critique was the common pattern they used all of the time in their classrooms. Accordingly, it was not necessary for them to explicitly plan *how to teach* for each lesson. It was already in their minds.

Setting cognitive goals.

Another routine they always had during planning was setting cognitive goals for their students. In particular, they set two different types of cognitive goals. One was a conceptual goal that was topic-specific and related to big ideas of science. For example, in the excerpt below, Steve explained learning expectations he set for his students when planning.

> The biggest goal was that the students walk away with a general sense of what force and motion is and what it's about. So, students understand the concepts like: the force is a push or pull, they understand that objects don't necessarily have force but they can apply a force. So, just setting foundation of what force and motion is and knowing that our conversation at times goes much deeper than that foundational level. That's ok but working on the core. We can recognize that there are forces acting on us all the time and we can explain the motions that are happening through the direction that's changed through measurement (Steve, 3rd interview).

As Steve stated, the teachers set different levels of conceptual goal based on their students' works on previous days. These different levels of conceptual goals were used to help individual students develop different levels of understanding as the teachers interacted with them in the classroom.

Another goal they designed and set during planning was an epistemological goal that was topic-general and connected to the practices and epistemology of science. Although they did not use the term 'epistemology' they discussed the practice of science and how science worked. For example, Janet asserted,

> The goal of this lesson was the whole practice of science, being able to look for patterns in data, to be able to analyze data and then to say, "What can I answer from what I have?" It's more science practice than science content at that time (Janet, VSR interview, lesson #3).

Janet set the goal in which her students should be engaged in understanding how science works and how scientific knowledge is developed—the definition of epistemology of science. Since these epistemological goals were topic general, they repeatedly applied similar goals to each lesson.

Moreover, the teachers integrated the epistemological goals with the conceptual goals. They believed that science knowledge and understanding of how science works (epistemology of science) should be integrated all of the time when a learning environment was created. From their perspective, conceptual goals and epistemological goals should be cohesively incorporated into classroom practices.

Designing resources that support the big idea.

In addition to setting clear learning goals or expectations, the group tended to collect and design resources, activities, or questions that could bring up some 'must know' science ideas or terminology their students did not naturally encounter. Through their previous experience teaching the unit, they built a collection of topic-specific resources they could use to help students understand particular science ideas. Using these resources, they said they roughly planned some activities, yet these would not be fully structured until they came to their classrooms and understood their students' prior knowledge and interests. Thus, the activities determined by the teachers during planning were plastic in nature. Teachers pre-arranged resources rather than predetermining structure.

Meanwhile, the teachers compiled a list of compelling questions or stories to initiate conversations on a particular topic or at least to evoke students' interest. They also prepared some thought-provoking questions to encourage students to connect their ideas and the big idea. These questions were driven by the teachers' previous experience and knowledge of teaching the particular topic. They said their students had similar difficulties every year, even though they had different background knowledge. Therefore, if there were any ideas that should be explored by students to prepare them to approach a big idea, they purposefully generated related questions or stories before the lesson.

In short, the most of the activities the teachers engaged in during planning were related to the cognitive dimension of science practice, in particular the conceptual dimension. They determined the science topic's big ideas, set clear conceptual goals, and outlined topic-specific concepts, resources, and questions that they could use to bring to the fore any particular scientific idea their students were expected to understand. In addition, they constantly considered the practices of science (epistemology of science) by setting an epistemological goal. This goal was considered to be one of the ultimate learning goals that students should achieve. Although they roughly determined what concepts and physical materials they might provide their students, they did not explicitly plan how to teach when planning. Rather, they implicitly applied the topic-general approach for every lesson.

Enacting decisions.

This section describes how the teachers consider three dimensions of practice when enacting their decisions. Interesting patterns of classroom instruction emerged through the analysis of the classroom videos and the interviews.

Cognitive dimension.

From the theoretical framework of this study, cognitive dimension should embrace both conceptual and epistemological aspects. Hence, the analysis of the cognitive practices focused on how the teachers took these two aspects into consideration when teaching.

Epistemological aspect: having constant negotiation.

A dominant pattern observed in their lessons regarding the epistemological aspects of science was constant negotiation—construct and critique. In most of their class time, the teachers provided their students with opportunities to constantly construct and critique their own ideas. Table 15 showed that the teachers devoted more than 70% of class time to engaging their students in epistemic practice, where students explored construction and critique of scientific knowledge. They believed their students could enhance conceptual understanding by persistently engaging in the construction and critique process, and this process should be embedded in all science practice.

Table 15. The Types of Classroom Practice

	Steve	Janet	Wilson
Epistemic Practice	82.8	82.3	73.4
Non-Epistemic Practice	17.1	17.6	26.6

In their classrooms, the students repeatedly shared their thoughts, critiqued each other's ideas, revised and clarified their thoughts through writing, and critiqued again through group discussion. It was a constant cycle. Through the cycle of negotiation, they believed their students built an understanding of a concept. For example, in an interview, Steve emphasized the cycle of negotiation is the hub of learning.

> I look at that back in the classroom and, you know, they don't just go and sit and write a test in isolation. They're constantly communicating, negotiating through what their test looks like. They're negotiating through what they think might happen and why. When we get to our claim and evidence it's all about the negotiation and communication, sharing of ideas and building (Steve, VSR, lesson #4).

He believed that his students learn science by constantly communicating and negotiating their ideas as scientists do. Hence, he was devoted to creating a learning environment where students could immerse themselves in the negotiation process all of the time. His beliefs about How to Learn and Evidence-Based Argument were reflected in his instruction.

Similarly, Janet viewed constant negotiation as a core practice of student learning. She encouraged her students to construct and critique their ideas because she believed students learn and understand better through continual negotiation. She said,

> I think getting them to see that they don't always have to agree with what someone else said. I can disagree. I can. My thinking may not be the same as theirs. It's ok to have a conversation about that. It's ok if we don't match. It's ok if my thinking wasn't accurate when we started. I can change my thinking or add on to it or scrap it and start over—whatever needs to happen. Just the idea that just because it could be accurate thinking doesn't mean they can't be critiqued or challenged or asked for more information. … As someone challenges my thinking, I have to change the way I word it, or I have to add something to it, or I have to come up with an example, that I'm getting better and my understanding is getting better and that's a good thing. I can learn more through critique and challenge and change and improvement (Janet, VSR, lesson #2),

Thus, her beliefs about How to Learn shaped her instruction, which emphasized constant negotiation when students learn. In both Steve and Janet's classroom, the constant negotiation process was evidently embedded in all practices as they intended and was not isolated from the conceptual understanding.

On the other hand, in Wilson's classroom, construction and critique was not constantly emphasized throughout all practices. He seemed to allot a certain amount of time for negotiation. He called it "negotiation time." Although he strongly believed that constant negotiation is extremely important for student learning, the negotiation process in his classroom was different. Nevertheless, all three teachers fostered students' conceptual understanding by engaging them in a constant negotiation process because they believed students learned science through construction and critique. This shows their beliefs about How to Learn formed their instruction for epistemic practice.

To encourage students to be engaged in constant negotiation, the teachers played two different roles. First they managed students' conversation by providing information and managing the space for negotiation. Sometimes they provided information to help them move to the next idea or question. This was not telling the students the answer but providing scaffolding. In addition, they often changed the space and mode of practice to foster student engagement in the negotiation process. For example, they kept changing the group modes to create different spaces for public and private negotiation. By engaging in both private and public negotiation, the students could solidify their conceptual understanding.

Secondly, they acted as a learner to help the students understand how to engage in constant negotiation process. Like students, the teachers actively shared their ideas and critiqued their students' ideas by participating in negotiation. Steve described,

> I think what I saw there were both roles, the management of the conversation, helping them move in the conversation so that we could be productive with the time that we had, but also trying to model for them that as a learner how we should be thinking through those things. So when I'm saying, "that was my thinking," or "I'm wondering," that's the language that they also start picking up too, or they start sharing it in that term rather than, "we should," it's "I'm wondering if we could." So it's now an idea that we play with rather than "this is what we're doing."… It's to get them to recognize that we're just putting and idea out and if it doesn't go that's okay, we just gotta share those ideas (Steve, VSR, lesson #2).

He was trying to model how students should think, critique, and build their ideas by acting like a learner. Thus, he showed his students how to learn by modeling it. Similarly, Janet and Wilson also played the role of learner when they encouraged student negotiation. Janet provided two reasons why she acted like a learner. She believed her students could see her as a genuine learner who did not have answers all of the time. As Steve mentioned in the excerpt above, this helped students recognize that they were just building ideas together rather than finding the "right" answer. Meanwhile, Janet also actually believed that she was "authentic learner" because she was still learning. She believed we are all learning all the time. which made her feel better because she, as a teacher, didn't necessarily know everything. Wilson also played the learner sometimes by actively critiquing his students' ideas and suggesting alternative ideas. However, he seemed to hold much more authority compared to Steve and Janet.

Conceptual aspect: making connections to big ideas in science

The most prevailing pattern observed in the three teachers' classrooms with regard to the conceptual aspect of science practice was that the three teachers repeatedly emphasized the big ideas during lessons. They managed classroom conversation to get their students to move towards a conceptual understanding of big ideas. With a clear conceptual goal, the teachers frequently reminded their students to go back to their big ideas for the unit. In addition, they actively jumped in their students' conversation and help them see what they were doing and how they could make connections between their ideas and the big ideas. For example, in the excerpt below, Steve began his lesson by encouraging his students to reflect on what the students had built on their ideas and how those ideas could be connected to the big ideas before they started a new investigation.

Steve:	But when you were actually going through the thinking through, "Why did it actually happen?", the claim and evidence, you actually went back and you were kind of informally running the test to get more of a picture of each of the pieces, right? So let's do that here. We've got two investigations, A and B. I don't care which is which. One was you change the…
Student C:	Height
Teacher:	Height. And one you changed the mass. Let's think through. What were the bottles doing? Remember, our big idea is "forces affect motion." So what are the two pieces that you really need to key in on?
Student A:	Forces and motion

Steve: Forces and motion. And you're looking for how those two are connected. Related. It says "affects." Alright, so, what one do you want to start with?

Student D: A, the height

Steve: The height investigation

Steve led the classroom conversation to assure that his students would stay focused on the big ideas during their investigation. In this conversation, he explicitly emphasized the importance of making connections to big ideas and reminded his students what they were doing for making these connections. In the VSR interview, he explained the reasons for this. According to him,

> If you're not constantly asking them to think about it, they don't always naturally think about it because they love to do it and that becomes the consuming thing. And running the investigations. Setting up their own investigation. They've never done that before. And so trying to keep that at the forefront: there's a reason we're doing this. And keep them understanding that's why we do this, why when you have question you can run an investigation but it has to relate back for it to help you and get information and just to make them see all those connection and reasons. They keep applying that as they go (Steve, VSR, lesson #2).

He presumed that teachers had to constantly ask their students to think about big ideas and compare them with their own because students can easily become distracted from this focus. By making connections between their ideas, what they were doing, and the big ideas of science, they were able to build an understanding. Given that he believed students learned by making connections between ideas, it seems reasonable to postulate that this instructional pattern stemmed from his belief about How to Learn. Janet also stressed the big ideas by asking questions like "Where does it make sense for us to keep going to figure out the big idea? (Lesson #1)". During the VSR interview, she frequently highlighted that the overarching goal of her instruction was helping her students build an understanding of the big idea (conceptual goal). By reminding her students of this conceptual goal, she encouraged them to think about how the different ideas and practices are related to the big ideas. Consequently, they could move forward to an improved understanding of a big idea. Similar to Janet and Steve, Wilson was also devoted to encouraging his students to think about the big ideas during the investigation. He was reflecting his lesson, stating as follows:

> What we were trying to do is, I was having them try to think about what was going on. They were supposed to take notes the day before. They were supposed to be able to use those notes, I was hoping they'd be able to use those notes to reflect back on the big idea, "force affects motion." So that was the purpose of this activity (Wilson, VSR, lesson #2).

He explicitly and implicitly set up practices where his students could think about the relationship between their ideas and the big ideas. In brief, all three teachers explicitly underlined their conceptual learning goal during lessons and strongly encouraged their students to be engaged in the learning process, and constantly negotiate and think about connections between their ideas and the big ideas.

To sum up, the teachers implemented cognitive aspects of science practice by shaping their instruction where a constant negotiation process was embedded, and the science big ideas were explicitly emphasized. However, one should note that these instructional practices are not separate from each other, rather they are integrated into instruction. In addition, the analysis demonstrated that these instructional practices driven by the cognitive dimension of science practice were mostly directed by their beliefs about learning—How to Learn and Control of Learning.

Social Dimension.

The teachers used different modes of language and different groups to create both private and public space for learning. In part I, it was revealed that the teachers believed students learn science through a process of private and public negotiation. This belief guided them to use language and group work as tools for creating a learning environment where private and public negotiation processes were embodied. Table 16 shows how much they used different modes of language and group practice.

Table 16. The Patterns of Using Language and Group Practices during Class

		Steve	Janet	Wilson
Language Practice	Talking	20.8%	44.2%	68.5%
	Writing	6.8%	3.1%	14.7%
	Talking +Writing	72.4%	34.9%	16.8%
Group Practice	Individual	6.8%	3.1%	14.7%
	Small group	25.7%	11.6%	21.9%
	Whole group	38.1%	85.3%	63.4%
No. of transition between modes of practice		10.3	3.5	3.0

The analysis indicated that the three teachers used talking practice more than writing practice. In addition, writing practice was frequently bounded with individual group practice. While Wilson tended to prefer using each mode of language separately, the other two teachers often used talking and writing together. In particular, Steve had his students constantly used talking and writing together, during more than 70% of his class time.

Another interesting pattern found through analysis was that Steve changed the mode of practice much more often than the other two teachers. Steve frequently switched the mode of practice (avg. 10.3/a lesson). By repeatedly changing the mode of practice, he could help all students engage in the practice without losing students' attention. This pattern predominated when he and his students were engaged in argumentation after investigation. He had his students constantly change the modes of practice to provide them opportunities to be engaged in both private and public negotiation processes. This pattern will be discussed below.

Language: using different modes of language

As already mentioned, all three teachers used different modes of language throughout the class. They all believed that language played a critical role in learning science. In particular, Steve and Janet helped students learn by incorporating different modes of language together into a practice. In their classrooms, the students constantly used writing while talking. They recorded their thoughts and ideas in their science journals and repeatedly revisited their ideas and revised them. While they believed both writing and talking were equally important, they supposed that each mode of language played a slightly different role in the learning process. In the excerpt below, Steve explained why he had his students engaged in both talking and writing.

> I think it does back to the idea where students need to have time to clarify their thinking and at times, just writing it out, students have probably said, "I didn't realize I didn't understand it until I had to write it out." So they're talking but they're not realizing what they're saying. When they're writing it, to be able to put it into words, written words. I guess, for me, when it's the verbal language, students are able to read each other. They're able to interject in each other's conversations. It's all built together. If you're not understanding, it can change what I'm saying. Where, in writing, I can't anticipate everything you don't know, and I am accountable by myself. In the textual sense, I've got to make it make sense from point A to D. And it's on me, it's not a group conversation anymore (Steve, 3rd interview).

He believed that students could clarify their thinking through writing and build meaning together through talking. In other words, writing helped student focus on private negotiation, while talking helped them to engage in public negotiation. Janet also agreed that writing enabled students to negotiate themselves by going back and forth to their ideas and talking enabled students to construct ideas together, by interacting with each other. From her perspective, talking is much easier than writing for students because students can easily change their ideas while negotiating. However, writing requires higher order thinking because students have to formally consolidate their understanding through writing. Evidently, he viewed and used language as epistemic tool that helped students construct and critique knowledge.

Compared to Janet and Steve, Wilson held less sophisticated beliefs about the use of language. Although he agreed that language is an important learning tool, he believed students should develop an understanding of science concepts in order to write about them. In particular, in his classroom, writing practices were often isolated from learning practices. He mainly used writing practice to test their prior knowledge and assess what they learned. During the class, his students recorded data from investigation but did not write their thoughts as much as Janet and Steve's students did.

Social interaction: setting different modes of group practice

In addition to using different modes of language, the teachers used different modes of group practice to create private and public negotiation spaces. All three teachers believed that individual practice was closely linked to students' private negotiation processes, while small group and whole class group practices were more closely connected to public negotiation processes. However, they emphasized that private negotiation happens all of the time. They presumed that students could have more of an opportunity to talk in a small group and teachers could hear more ideas from more students. On the other hand, they tended to use a whole-group practice when they wanted to discuss the important idea on which their students were expected to agree. Janet explained,

> They're not going to get better if you leave them all by themselves. At that point, you have recognized when you can go back and forth. When is it ok to work with all the people who understand it together and when is it ok that we need to be mixed up. Does that make sense? That was an important conversation for them to understand. We need to talk about

> this as a whole class because we need all the answers as a whole class. Our whole class has determined that this was the important information, so our whole class should make the decision on what we're doing. If your group determined that was your question, then you can leave your group to determine what should be happening, but our whole class has determined this is important, so our whole class needs to be involved in giving input into what we're doing with this test (Janet, 3rd interview).

By switching the modes of group work between small groups and the whole group, the teacher could align ideas. Then, students could cross-check, by engaging in different group practices. This type of instruction appeared to be related to beliefs about Sources of Knowledge and Justification of Knowing. The teachers reasoned that students could construct and justify their knowledge better if they saw different ideas from different groups.

Meanwhile, they also believed that different modes of group practice also affected the level of student engagement. Wilson stated that in a whole group they could easily lose students' attention, hence teacher should change the modes of group practice. In the VSR interview, he was reflecting on his instruction, saying as follows:

> Fins. We started out, everybody was engaged, but as time went on, we started losing some. What I should have done was once we started losing some, pair up in a group, start having discussions, report back as a group and I'm gonna just, I could say, there's four in a group, and I'm just gonna draw a number and who whatever number that is in the group, you gotta be the spokesperson. That way, everybody stays engaged, you've gotta tell, what's your group's consensus. Instead, we went full group and as we went on and on and on, we still had lots of people arguing, and but there was two or three main people focused and you started losing the other kids around the outside. That's the trouble

sometimes when you go large group, you start losing some of the engagement of the others (Wilson, 3rd).

He thought he lost some of his students' attention because he had his students grouped as one for a long time. As shown in Table 16, Wilson set up whole-group practice more than small-group or individual practice. Moreover, in his classroom, whole-group conversations were mostly led by him. Although he mainly discussed student-oriented ideas with the whole group, some of his students were not engaged in the conversation. In contrast, although Janet and her students also spent much more time in a whole-group rather than individual- or small-group setting, the whole-group conversations were mostly directed by her students. Thus, her students' engagement level was quite a bit higher than that of Wilson's students.

In short, although the patterns of using language and group practice were different, the teachers used these dimensions to create classroom dynamic. More importantly, they believed it was important for students to have dynamic learning environment where they could constantly engage in both private and public negotiation, as well as the knowledge construction and justification process. Thus, they viewed and used language and group practice as epistemological tools. In addition, their beliefs about learning and knowing (epistemological beliefs) were reflected in these instructional decisions.

Physical dimension.

Physical resources.

The teachers' classrooms frequently used three types of physical material: 1) a science notebook, 2) books and Websites, and 3) experimental resources.

Science notebook.

Although student notebooks are not designed by teachers, the teachers regarded the student notebooks as an important learning tool/resource and tended to strongly encourage their students to use the notebooks all of the time. However, by closely looking at their instructional practices and underlying beliefs on the use of notebooks, the analysis revealed that there were some differences between the cases.

Apparently, science notebooks were constantly used as learning tools in Steve's classroom. His students naturally and constantly recorded their thoughts and learning procedures in their notebooks without his instruction. Indeed, he rarely mentioned student notebooks in the classroom. In fact, he did not collect or grade their notebooks at the end of the unit because he believed it was for the students' learning. In his interview, he explained his thoughts about student notebook.

"It's for students to record their idea and to have that private negotiation when needed. A place to write and record and go back and look and reflect. It's a place to, for example, when we're in the whole group, they can write down their questions or write down their thinking to go back to later. Ideally, students would start saying, 'Here's what we talked about. We're 2 days down the road.' Instead of forgetting it, it's: 'here's my journal'. It's a place for me to help remember what we've done (Steve, 2nd interview)."

Although Steve did not explicitly mention or emphasize the notebooks in his classroom, he frequently had his students think back on what they understood, what they knew, and how they developed their ideas. Thus, his students were expected to return or revisit to their previous thoughts and understanding that they recorded in their notebooks.

Since he did not provide a template or structure for the notebook, his students organized theirs in their own styles. However, there were consistent components that most students had in their notebooks: the big idea, a concept map, questions, beginning ideas, a "what-I-understand-now" statement, the design and procedures of investigation, and their reflections. Most of these components were consistent with class activities that were designed by the teacher. By constantly recording their thoughts and by revisiting what they had in their notebook throughout the practice, the students were able to make connections between their thoughts, data, big ideas, and other people's ideas. Instead of explicitly emphasizing the notebooks, Steve provided sufficient time and space for students to write down their thoughts. He seemed to implicitly place cognitive demands required for his students to use their notebook as an epistemological tool for constructing their own knowledge.

On the other hand, Janet tended to explicitly express expectations about the science notebooks to her students. She often asked them to take time to write down their thoughts while working in a group. She collected her student notebooks without grading them at the end of the unit. While she believed that writing is as important as talking, and asserted that it was different for her students to be naturally engaged in writing. However, as Steve did, she presumed that the notebook enabled her students to build their knowledge through fostering private negotiation. The students could see how the different ideas were connected to each other and how their understanding had developed, through what had been recorded in the notebook. Namely, she also used the notebook as learning tool and epistemological tool

Compared to Steve and Janet, Wilson placed less emphasis or lower cognitive demands on using the notebook. Given that he believed students should develop a good understanding of a concept before they wrote about it, it was not surprising that he infrequently emphasized or encouraged his students to use the notebooks during learning processes. Although his students recorded their data and procedures of their investigation in the notebook, they rarely put in their own ideas and thoughts.

Books & Websites.

Books and Internet sites were other physical materials that all three teachers used to bring external sources for their students. In particular, they used these sources when they believed their students needed to have expert consultation on a particular idea. Janet said,

> I try to make sure I have either a website or a book or something that I've gotten from other teachers that we can agree is what we want them to come out understanding about that topic. Then I will interject it into different groups and be like, "Hey Mr. S's class found this out. Last night I was on the internet and I found this, maybe it's helpful." Sometimes I just walk up and put it on their desk and they either chose to read it or they don't. That's a way I can hit the struggling readers who I know don't read very well. If they're having trouble reading or understanding an internet site, I will already have a text that I know that I can give them. It gives them opportunity to get in the conversation and also gets them to have the information that I want them to come to an agreement on. That is a place where I can interject hat information (Janet, VSR, Lesson #4).

In this excerpt, Janet believed that the external sources would help her students justify their understanding and make better conclusions. However, according to the teachers, the students often struggled to make conclusions based on what they found from the investigation. Therefore, the teachers provided their students with opportunities to compare multiple lines of evidence that they could find in books or Websites.

This instructional practice seemed to come from their beliefs about Justification of Knowing. They believed that by generating and comparing evidence from multiple sources, one can clearly acknowledged what they know and which ideas are better than others. Rather than accepting without doubts what the experts said, they encouraged their students to think about what evidence the experts provided. That is, they emphasized that external information, including expert reports, are the resources that students should question and compare.

Experimental materials.

The teachers collected a bank of resources over the years, based on their experiences of teaching the same topic. According to them, they planned and designed a few formal investigations that were repeated every year for a particular unit. For these investigations, all experimental materials were ready for their students. For example, for the 'Force and Motion' unit, all three teachers prepared enough ramps and cars, and catapults. They said they selected those materials because they believed they brought up important ideas their students should explore through investigation. Thus, they chose the materials based on their knowledge and experience. Still, how they used the materials came from their own beliefs about student learning. They provided these materials to their students and had conversations about how they could use these materials to design their own investigation and to answer their own questions. Namely, while they used the limited experimental materials, they did not limit the opportunities and ownership that their students could have in designing and testing their own investigations. Apparently, this instructional decision, regarding how to use the materials, was made based on their beliefs about learning. Steve highlighted that his way of using instructional materials changed as his beliefs about learning changed, stating that "I know we had some FOSS kit things that we pulled out and we're now using them differently, some different toys—for example, in the force and motion we can use them to, to understand force and motion. (Steve, 2nd interview)"

Time Resource.

In all three teachers' classrooms, time was a thing that the teachers controlled and managed throughout the lessons. According to them, they did not predetermine how much time they would spend on each practice, rather they decided it based on their students' needs. Steve explained how he managed time in class, by providing an example:

"I guess, when the students are privately negotiating, for example, with tests and they're writing, I'm just going around reading over their shoulders, taking a look at what they wrote. I can notice when pens are slowing down. They start setting them down. They start relaxing. They're done. So I don't go into it. I think I do say, "I'll give you 5 minutes to write." But my 5 minutes is more just a frame of reference for them to say, "I have some time to do a little writing and a little thinking." So it's not necessarily 5 minutes on the clock. I try to keep it somewhere around 5 but it's more like 4 to 10. It's based on what they need. "(Steve, 3rd)

He made decisions based on what his students need in class. To make appropriate decisions on time, he constantly paid attentions to students' learning progresses. He tried to provide sufficient time and space for students to clarify their thinking and develop their own understanding. Janet and Wilson also emphasized that they tried to decide time based on students' needs. In particular, Janet often asked students to decide by themselves how much time they needed for doing their investigations. If she thought they were running short on time, she explained it to her students and guided them to make feasible decisions. In short, all three teachers managed time based on students' needs, not their needs.

Dialogical Interaction.

To understand how the teachers developed and engaged in dialogical interaction with students, this study analyzed the patterns of "teacher talk." The patterns of talk were analyzed based on types, focus, nature and function. Two themes emerged through the analysis.

As discussed earlier, it was evident that all three teachers were willing to give their students ownership of their ideas all of the time. They were devoted to creating a student-centered learning environment where their students could share ideas and build meaning together. Consistently, the analysis of teacher talks also indicated that the focus of classroom dialogue was predominantly student-oriented ideas, not teacher-oriented ideas. Table 17 presents the percentage of classroom discourse spent on either student or teacher ideas. More than 80% of classroom turn taking involved student-oriented ideas, showing that the student voice was significantly respected in these classrooms.

However, this does not merely mean that the students talked more than their teachers or the students predominantly led classroom conversations. Rather this showed most classroom conversations centered on student ideas, even though the conversations were led by teachers. Indeed, more than 30% of turn taking was used by the teachers (Steve: 34%, Janet: 31%, and Wilson: 49%). Given that more than 20 students were with one teacher, the 30% of turn taking by a teacher was not trivial.

This shows that the teachers actively participated in classroom conversation but discussed around student-oriented ideas.

Table 17. Focus of Classroom Talk

			Steve	**Janet**	**Wilson**
Avg. # of turn taking by teacher	*Teacher-turn taking /a lesson*		193/539 (34%)	154/480 (31%)	123/254 (49%)
Focus of Talk	*Student ideas*	SI	70.6%	71.7%	70.7%
	Teacher ideas	TI	13.1%	17.0%	18.9%
	Both	SI/TI	16.3%	11.3%	10.2%

Moreover, the analysis indicates that the three teachers used more epistemic talk such as reflective tossing, clarifying, challenging students' idea, and pumping, than initiation talk. Initiation talk describes a teacher's question or statement to start classroom discussion, introduce new topic or elicit students' understandings related to concepts. On the other hand, epistemic talk indicates a teacher's questions or statements in response to students' previous comments and ideas. As seen in Table 18, all three teachers used epistemic talk more frequently than initiation talk, suggesting that their dialogical interactions were mostly created around students' ideas.

Table 18. Nature of Teacher Talk

	Steve	Janet	Wilson
Initiation talk	35.0	21.2	24.3
Epistemic talk	64.9	78.8	75.6

More importantly, the analysis of teacher reasoning revealed that the teachers valued student-oriented ideas because they believed that the students were charged with their own learning (beliefs about Control of Learning). In an interview, Janet reflected on her teaching by saying that,

> To me that's what learning is about. It's been instilled from Bill [a PD leader] as well that I'm not in charge. So why not give them the opportunity to have the ownership? And if that it's something they wanted to know the answer to, then they'll be more engaged and have more investment in wanting to. As opposed to: "Well, that's a question you really want to know, so why do I really care whether I get the answer or not? You wanted to know it instead of me." I think getting them to understand. I also think that's just how it works. When I want to know something, I ask a question, and I try to figure it out. So wanting them to also understand that you don't—you know—when you want to know something, there's a process. You don't have to wait and see if a teacher asks that question. If you want to know, ask a question. Figure out how to answer it (Janet, 3rd interview).

As Janet said, all three teachers heavily valued student-oriented ideas because they believed it was students who were in control of their learning. Although the ways of developing dialogue centered on student-oriented ideas were different, it was recognizable that their beliefs about Control of Learning centered their instruction on student-oriented ideas.

To center instruction around students' ideas, the teachers played roles as careful listeners in classroom dialogue. The teachers asserted that they could have a few benefits from being a careful listener. By being a listener, they could provide more power or authorities to their students. Moreover, they were able to understand how much their students develop understanding of a science concept. Janet insisted,

> That gives me more of a reflection. If I'm leading the conversation, it's hard to keep track of everybody because I'm constantly having to change my conversation to whoever's speaking whereas if they're working together, I have that opportunity to reflect and see where they're going and then be able to make decisions on what needs to happen next (Janet, VSR, lesson #6).

As Janet highlighted, this also gave the teachers an opportunity to sit back and see how much students were engaged in the practices they created and how much their instruction was effective for the students in learning a concept. Thus, by acting as listener, they could make better decisions on how to help.

To sum up, the teachers created student-centered learning environments by focusing on student-oriented ideas during dialogical interactions. This instructional pattern was stemmed from their beliefs about Control of learning.

Conceptual model of instructional practice.

Through the analysis of classroom practices and interviews, the conceptual model of instructional practices that explain how the three dimensions of science practice should be incorporated into cohesive instruction was developed. As seen in Figure 7, the cognitive dimension (or conceptual and epistemological aspects) drives classroom discourse toward the desired cognitive goal. Teachers can help students develop conceptual understanding of big ideas by engaging them in constant negotiation (construction and critique) processes and by placing an explicit emphasis on making connections to the big ideas throughout the practice.

To create learning environments where constant negotiation is valued, teachers use different language and group modes as epistemological tools. In other words, they frame language and group modes to create private and public negotiation spaces. Physical materials and time are also used in a way that foster students as the authorities/power in the knowledge-construction process. In addition, classroom dialogue should be centered on student-oriented ideas and those students' ideas become to get close to a big idea through constant negotiation.

Summary

In this chapter, I described the essential elements of EOTS around two themes. In part I, the essential elements that all three teachers firmly held were presented. Among 17 theoretical elements that were conceived through literature review, only 11 elements were identified as essential beliefs that the teachers shared and were interconnected to each other. In addition, beliefs about learning had most connections to others, suggesting that it is central beliefs that shaped the learning-centered EOTS. The alignment between beliefs about knowledge in general, knowledge in science, learning and teaching established a strong foundation of EOTS.

In part II, patterns of the teachers' instructional practices were addressed. In planning, the teachers did not pre-determined *how* to teach while they clearly planned *what* to teach. During the lessons, the teachers created a learning environment where students develop their own conceptual understandings of science by explicitly placing an emphasis on making connections to big ideas in science and by addressing constant negotiation process. The analysis of the VSR interviews revealed that these patterns of instructions were influenced mostly by their beliefs about How to Learn, Control of Learning, Source of Knowledge, and Evidence-based Argument. Meanwhile, they used language practices and social group works to create spaces for the students to be engaged in private and public negotiation. Time and physical materials, including science notebooks, books, websites, and experimental tools were also used in the way that supported students to make connections between multiple sources of information. Moreover, the classroom dialogues were generated around student-oriented ideas and the teachers used epistemic talks more than initiate talks when interacting with their students.

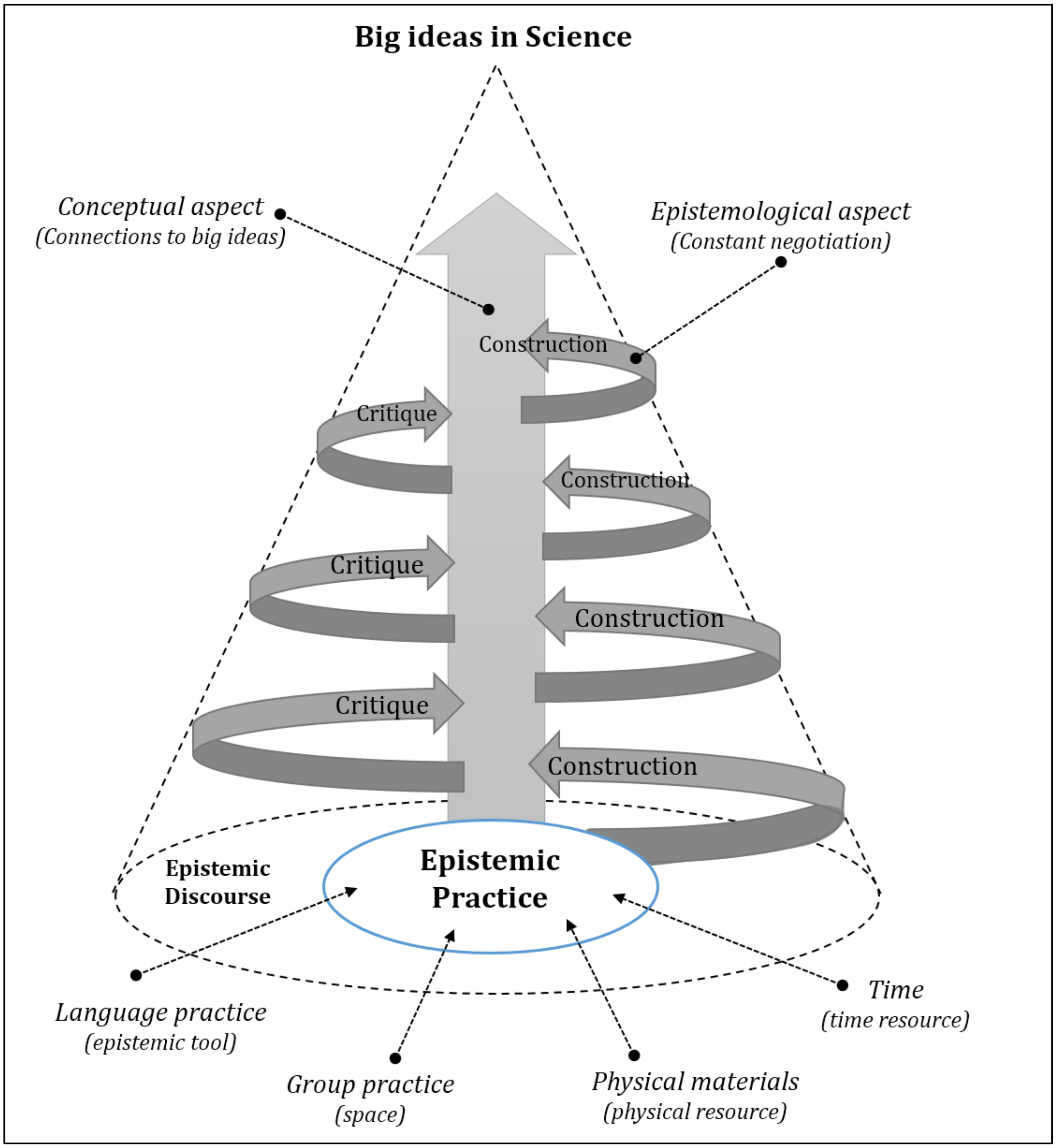

Figure 7. Conceptual Model of Instructional Practice

CHAPTER FIVE

DISCUSSION

The questions that framed this research focused on identifying essential elements of the Epistemic Orientation toward Teaching Science (EOTS) and examining how these elements are reflected in the instructional practices that foster student engagement in science practice. This study views teachers as decision makers who must choose desirable values for students based on their beliefs. This view is based on the assumption that beliefs are the best indicators of the decisions teachers make (Bandura, 1986; Pajares, 1992; Taylor, 1990). While many studies on teaching focused on whether teachers' beliefs align with their instructional practices by defining and categorizing different beliefs and practices, this study aimed to identify essential beliefs that *should* be the target of teacher development, from a reform perspective. In this chapter, I discuss findings from this study around three themes: 1) critical features of the EOTS, 2) the relationship between the EOTS and three dimensional instructional practices, and 3) conceptualization of learning-centered EOTS.

Critical Features of the EOTS

To develop a comprehensive model that explains the interrelationship of beliefs to orientation, this study identified 11 distinct beliefs about nature of knowledge and knowing, learning, and science that the three exemplary teachers commonly held. The conceptual model developed through this study describes several prominent features of the EOTS (see Figure 8).

Explicit Beliefs

Nature of Knowing - Alignment

G2: What I know now came from my self-construction and interaction with other people.
S2: Scientific knowledge is advanced through argumentation.
L2: Students learn best by negotiating meaning between their own knowledge and the new knowledge.
T2: Teachers should provide their students with opportunities to negotiate and challenge each other about their ideas.

Justification of Knowing

G3: I justify my knowledge based on all of my evidence (multiple sources) and my reasoning.
S3: I believe scientific knowledge is based on multiple lines of empirical evidence

Control of learning

L3: Students are in control of their learning.
T1: Teachers are managing classroom environment.

Implicit Beliefs

Knowledge

G1: What we know today can change tomorrow.
S1: scientific knowledge can be change with time.

Student ability

L1: All students can reach a certain level of understanding if they are motivated to work.

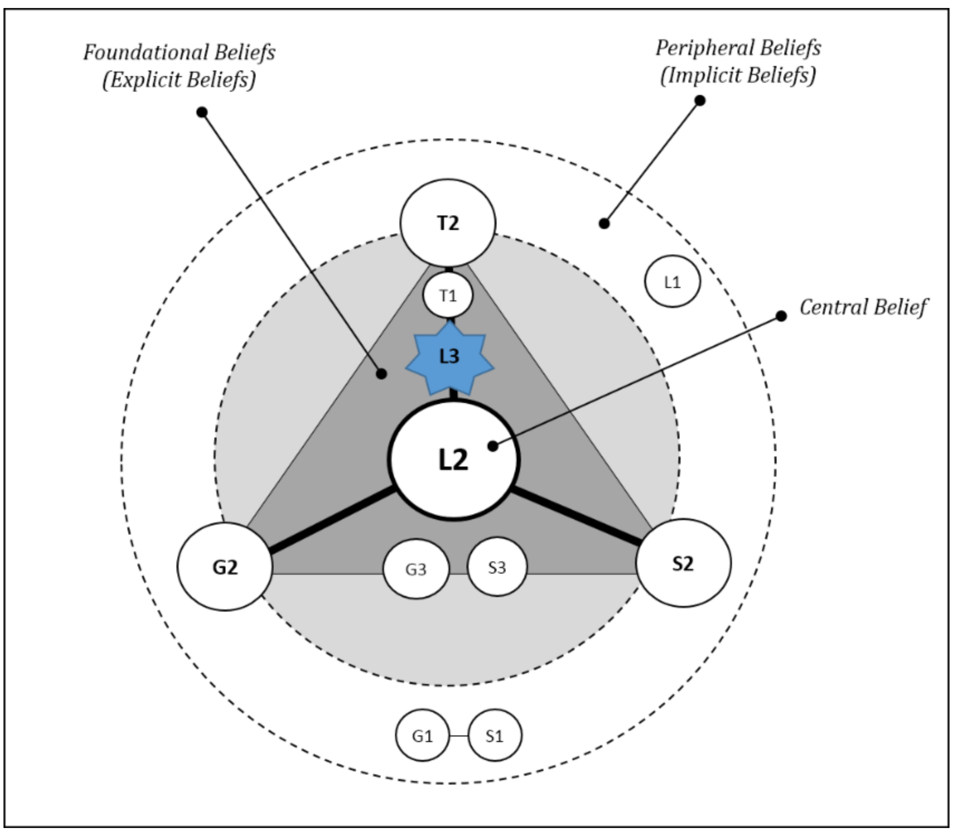

Figure 8. Revised Model of EOTS

First, this study empirically supports the importance of teachers' beliefs about learning, in particular How to Learn (L2). As Martin (2008) suggested in her study, the belief about How to Learn (L2) was a central belief on which the other beliefs hinge. In a belief system, some beliefs are considered to be more central than others (Rokeach, 1968). Central beliefs of a teacher are determined by two factors: 1) whether they are professed and/or enacted (Bryan, 2003; Haney & Macarthur, 2002; Levitt, 2002), and 2) whether they have more connections to other beliefs (Rokeach, 1968). In this study, How to Learn (L2) was most connected to other beliefs and enacted most while teaching science. The teachers paid a good deal of attention to *how* their students learned when making decisions and tried to adjust their teaching to be aligned with it. In short, their instructions were mainly directed by their beliefs about How to Learn.

Moreover, the teachers in this study emphasized that their orientation to teaching had shifted as their beliefs about learning changed. Given that the entire orientation system is affected by the change of core beliefs, How to Learn (L2) played a critical role as a core belief to change their entire orientation. Specifically, this belief came to be central as the teachers developed a strong understanding of how students learn through the Science Writing Heuristic (SWH) Professional Development (PD) programs and their experience of teaching the new approach. The results align with research suggesting even experienced teachers could benefit from PDs focusing on the nature of student learning (Boulton-Lewis et al., 2001). Unlike the conventional PDs which can be fragmented 'one-shot' workshops, the SWH PDs encouraged teachers to be engaged in their own learning process. The teachers in this study stressed that they were uncertain about how students learn and had not even thought about it before they were trained by the SWH PD programs. Before shifting their beliefs about learning, they taught science in the way that they believed it should be which were mostly drawn from their science learning experiences as students. As seen in the Figure 9, their beliefs about teaching, learning, science, and knowledge were separate or weakly connected to each other. Although each of these beliefs had been developed throughout their lives, these beliefs were neither firmly attached to each other nor used in conceptualizing teaching. In their current belief system, however, these beliefs were strongly interconnected. As the experienced teachers developed new ideas about how students learn, they began to make connections between the ideas regarding knowing, learning, science and teaching. Accordingly, it seems reasonable to conclude that the beliefs about How to Learn (L2) leads the paradigmatic shift.

The findings also point to the significance of *cognitive conflict*. During the learning session in the PDs, the teachers' ideas about learning were challenged by the PD leaders and the teachers experienced *dissonance* between what they believed about how students learn and how they actually taught in their classrooms. That is, the substantial learning opportunity offered by the SWH PDs initiated cognitive conflict between what they know and what they did. As Cobb, Wood, and Yackel (1990) suggested, challenges to teachers' beliefs and thoughts, or *cognitive conflict*, motivated change. This might be more important for experienced teachers who could be more reluctant to give up their pedagogical strategies (Bright & Yore 2002;

Yip 2001). Without experiencing dissonance, experienced teachers might not be motivated to change.

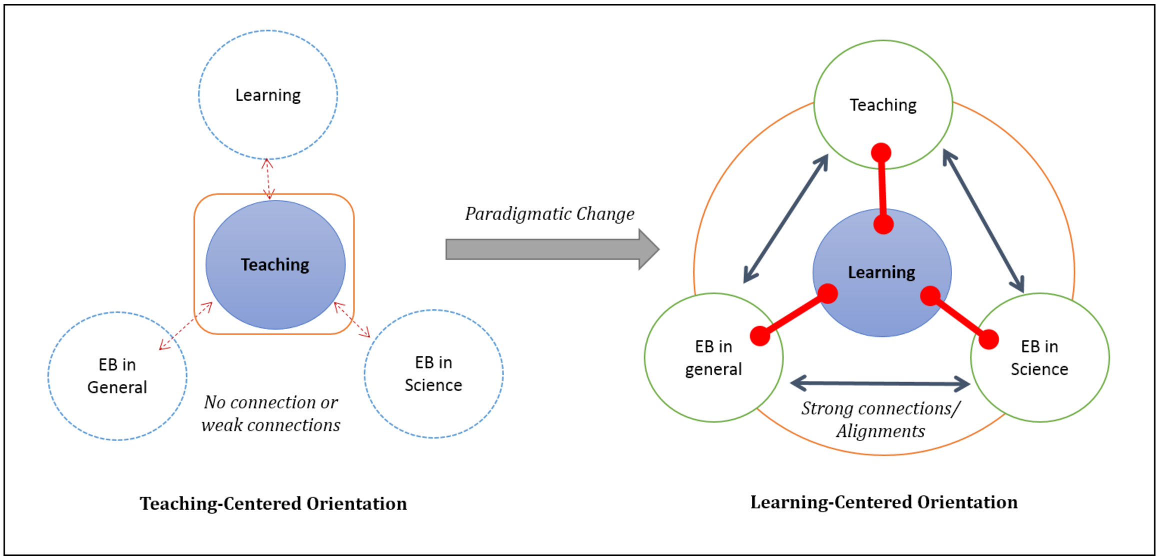

Figure 9. Paradigmatic Change in EOTS

Despite the importance of the belief about how students learn, the issue has garnered little attention from studies about teacher beliefs and practices (Martin, 2008). Some research suggests that a limited understanding of student learning often causes weak connections between teaching and learning. Bryan (2003) reported that a preservice teacher held at least two different beliefs about how students learn science and these beliefs were influenced by the teacher's foundational beliefs: the *value of science* and *science teaching*, the *nature of scientific knowledge*, and *goals of science instruction*. Interestingly, the beliefs of the preservice teacher in Bryan's (2003) study appeared to be consistent with those beliefs held by teachers in this study, before their beliefs and instructions shifted. The preservice teacher's limited understanding of the epistemological basis of constructivism led her to hold two different nested beliefs about how students learn science and to develop weak connections between beliefs about learning and teaching (Bryan, 2003). In turn, the practice of the preservice teacher was more teacher-centered.

Second, while the belief about How to Learn (L2) drove paradigmatic changes in the whole orientation system, the Control of Learning (L3) seemed to *initiate* a paradigmatic change in the relationship between beliefs about learning and teaching. This belief can be considered a subset of the belief about How to Learn. Nevertheless, in this study, this belief was distinguishable and often surfaced separately. The Control of Learning concerns the epistemic power relationship between students and teachers. It is an important issue for both students and a teacher to determine who controls learning in the classroom. Teachers with teacher-centered views typically believe that teachers should control everything in the classroom and often confront dilemmas related to classroom management when they were encouraged to shift their practices away from a teacher-centered approach toward a student-centered approach (Bryan, 2003). The teachers in this study repeatedly highlighted that they began to pay attention to how students learn when they realized that students were in charge of their own learning and a teacher had no control over what is going on in students' minds. In addition, this belief affected their beliefs about the Role of Teacher. They shifted their roles from primary source of knowledge to classroom manager or resource person as they changed their epistemological position for classroom control. It was a paradigmatic change that occurred when the fundamental ideas about learning and teaching changed. Accordingly, the Control of Learning was a critical element that initiated this paradigmatic change in orientation.

Third, to understand how the teachers developed strong learning-centered orientations, we should also acknowledge that the alignment between the four major beliefs established a strong foundation for the EOTS. The four major beliefs include Source of Knowledge, How to Learn, Evidence-based Argument, and How to Teach. These beliefs are fundamentally concerned with how we develop knowledge and what conditions are needed for knowledge development. These are about epistemological bases of general and scientific knowledge development, learning, and teaching. While the epistemic underpinnings of these four beliefs are theoretically consistent with each other, researchers did not explore whether these beliefs must align when teachers conceptualize teaching. Although a few studies described links between epistemological beliefs and beliefs about teaching and learning in general (Brownlee, 2003; Entwistle et al., 2000), there has been no study investigating the four beliefs together: beliefs about knowledge in general, knowledge in science, learning, and teaching. On the other hand, some researchers have examined the relationships between beliefs about knowledge in science and learning and teaching. For example, Aguirre et al. (1990) and Gustafson and Rowell (1995) demonstrated some linkages among science teachers' views about learning, teaching, and science, without suggesting how they operated together when a person conceptualizes teaching. Tsai (2002) also suggests that a teacher's beliefs of learning science, teaching science, and the nature of science seem to be closely aligned, yet did not provide evidence showing how this alignment is related to teaching science.

With this in mind, this study suggests that the development of this alignment is important for teachers aiming to strengthen their epistemic orientation to teaching. As discussed earlier, the teachers study had weak connections between these beliefs before participating in the SWH PDs. They paid close attention to what and how they taught rather than how students learn. According to them, it was obviously a teacher/teaching-centered view. They might also hold dualistic ideas about knowledge, science, learning and teaching, as did the preservice teacher shown in Bryan's (2003) study.

As teachers began to build new ideas about learning and consider how students learn, they came to develop a more learning-centered orientation to teaching by making connections between how they come to know (epistemology in general), how science works (epistemology in science), how students learn (learning), and how teachers should help students learn (teaching). This process is apparently consistent with how one comes to know something. All three teachers presumed that they seek an alignment across multiple sources when they develop and justify their understandings of a particular idea. Thus, by comparing the different ideas, they came to see epistemic alignment across different ideas and this enabled them to develop a stronger epistemic orientation. Although we should note that their changes may not be perfectly reflect the intended reform, it at least seems clear that alignment plays a critical role in shaping a strong EOTS.

Lastly, the conceptual model of this study also describes that the 11 essential elements are nested within each other and are not always separable entities as previous research suggested (e.g. Feucht, 2011; Wallace & Kang, 2004). For instance, as the teachers discussed how they came to know, they often made connections to how students learn. As discussed above, these types of connections are important, as they strengthened the orientation to teaching. Moreover, some of elements were more explicit than others while others were more implicit and embedded in other beliefs. Therefore, this study categorized the beliefs into two groups: *explicit* (foundational) and *implicit* (peripheral). As shown in Figure 8, G2, S2, L2, T2, G3, S3, L3, and T1 were *explicit* and *foundational* (and frequently used in instructional decision-making processes). On the other hand, G1, S1, L1 were *implicit*. Implicit beliefs are not less important, but rather, less explicitly presented when conceptualizing teaching. While inclusion of explicit beliefs seemed obvious, the implicit beliefs required a closer look to before the relationship was evident.

The relationship between the EOTS and instructional practices

Contemporary science education establishes that teachers play an essential role in shaping how learning occurs in a classroom where science practices are emphasized (Harris & Rooks, 2010). Nevertheless, the notion of teaching science through science practice has been ill-defined in science education research (Windschitl et al., 2012). Even though numerous lines of research have focused on how to teach science through science practices, with broad concepts such as reform-based approach, inquiry, hands-on activity, or doing science (e.g., Beerer & Bodzin, 2004; Crawford, 2007; Moscovici, 1999; Volkmann & Abell, 2003), the concept was ill-defined (Gess-Newsom & Lederman, 1993; Ingersoll, 1996). Indeed, such studies do not guide novice teachers in how best to embody critical features of science practice in a learning environment. In this regard, this study depicts a big picture and how the three exemplary teachers incorporate multi-facet of science practice into cohesive instruction. Figure 10 illustrates how the three teachers managed classroom conditions by considering cognitive, social and physical dimensions of practice. In particular, the figure illustrates the areas of management that need to be attended to when teaching, highlighting what the teachers least controlled and most control. The concept of management here is different from the classroom management that concerns student behavioral issues. Here, management concerns creating conditions for students to be able to learn as they engaged in science practices.

First of all, this study revealed that the teachers focused on the developing a conceptual understanding rather than doing activities. It has been documented that science teachers in U.S. focus on activity rather than sense making (Roth et al. 2006). Quite differently, the teachers in this study paid more attention to how students developed a conceptual understanding of science through scientific reasoning, than on activities or skills. This was apparently shown in the patterns that the teachers incorporated into the cognitive dimension of their instructional practice. From the theoretical framework of this study, the cognitive dimension encompasses the ultimate goals for teaching science: helping students develop a conceptual understanding of big ideas in science and a grasp the epistemology of science. Figure 10 shows how the teachers managed learning environments to help students achieve these ultimate goals.

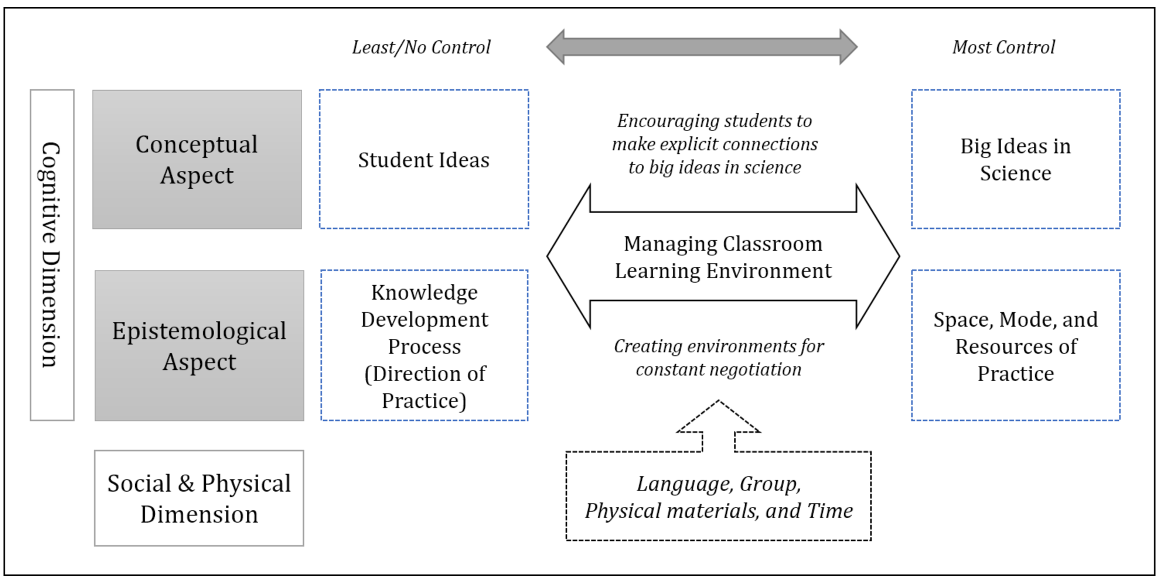

Figure 10. Instruction for Science Practice

To foster students' conceptual understanding of big ideas in science, the teachers explicitly and repeatedly emphasized them throughout the lessons. They encouraged students to make connections between what they generated from investigation, what they knew, what they heard from others, and big ideas. Instead of focusing on each practice, they stressed how the practices they did were related to the understanding of big ideas. That is, they managed classroom knowledge to help students see how multiple lines of evidence could be connected to big ideas in science without controlling students' ideas. This pattern of practice mainly stemmed from their beliefs about the Source of Knowing (G2), How to Learn (L2) and Evidence-Based Argument (S2). The process they encouraged their students to engage when making sense of science perfectly reflected how they believed they came to know (Source of knowing) and how science was advanced (Evidence-based Argument). Ford (2008) pointed out that constructivism often regards scientific ideas as same as everyday ideas and views authority as freedom to make sense as one wishes, suggesting scientific sense making should be underlined in the science classroom. While the teachers had their students engaged in their own sense making process, they also emphasized that the students' ideas should be accountable for explaining the big ideas of science in light of evidence generated from multiple sources.

In addition, the findings demonstrated that the exemplary teachers paid close attention to the epistemology underlying science practice. Instead of placing emphasis on each practice, they stressed a whole negotiation process. In the classrooms of the three teachers, each science practice was not viewed as a separate or independent practice but as an integrated and interconnected epistemic practice that addressed scientific reasoning patterns and epistemology of science. In particular, they created the conditions for constant negotiation because they believed learning was cycle of negotiation --- construction, and critique, and this reflected the epistemology of science. Duschl and Osborne (2002) stressed that scientific inquiry must address "epistemic goals that focus on how we know what we know, and why we believe the beliefs of science to be superior or more fruitful than competing viewpoints." While several researchers showed how the epistemic goals are taken into consideration by proposing different criteria and principles, they agreed that at least two epistemic features need to be addressed: 1) giving students authority to construct knowledge (Ball & Bass, 2001; Cobb, Gravemeijer, Yackel, McClain, & Whitenack, 1997; Lampert, 1990) and 2) encouraging them hold accountability to the shared disciplinary norms (Resnick & Hall, 2001). These two features predominated throughout the teachers' lessons. Although the conceptual connectedness of science practice and integrated sense-making practices have been emphasized in reform documents (NRC, 2007, 2012), in general, these features are rarely observed in science classrooms, even in the classrooms of experienced teachers (Driver, Newton, &Osborne, 2000; Lemke, 1990; Mehan, 1979; Weiss et al., 2003). While research argues that teaching through science practice is epistemologically different from traditional teaching, this study shows that development of a strong EOTS can influence a teacher's awareness of these epistemic underpinnings of science practice and enable one to address the theoretical basis throughout their lessons.

The findings of this study also suggest that a strong EOTS led the teachers to shape their instruction around student ideas; this addressed both conceptual and epistemic goals. Ford (2008) expressed his concerns that science instructions often overemphasized construction of knowledge without necessary attention to critique. This problem seems to originate in a lacks of understanding of the relationship between conceptual and epistemic goals for teaching and learning science. As he discussed in his study, students do not construct new knowledge, but develop conceptual understandings of old (settled) scientific knowledge (Ford, 2008). Therefore, while teachers have their students develop their own understandings, they also need to emphasize that the students should develop a conceptual understanding of big ideas in science. The NGSS also underlines the importance of integrating conceptual and epistemic aspects into science practice. Although the teachers did not explicitly mention conceptual and epistemic aspects of science practice, they addressed the two aspects together throughout their instructional practice. Moreover, their instructions originated in their beliefs about How to Learn (L2) and Evidence-based Argument (S2). They believed that students should develop a conceptual understanding through construction and critique, and this required making meaning in light of evidence-based argument. More importantly, their strong EOTS enabled them to see the alignment between these ideas, and in turn, to incorporate the conceptual and epistemic goals into science practice.

Another important pattern that emerged was the use of language as an epistemic tool. Although researchers acknowledge that language plays a critical role in science practice (Gee, 2004; Hand, 2008; Norris & Phillips), few studies have focused on how teachers use language in the science classroom. In this study the teachers used language as epistemic tool to help students engage in construction and critique. Linell (1998) explained that language can be conceptualized from two perspectives. First, from a formalist perspective, language is seen as a system or structure. According to this perspective, language is regarded as a value-free or neutral form for describing and representing phenomena or ideas. Second, language is viewed as discourse. From this position, language is not viewed as a value-free representation tool or structure, but as part of communicative or cognitive practices. In a teacher-centered classroom, language is often used as precise, neutral forms or structure to describe and deliver accurate knowledge. However, the teachers in this study viewed language as part of cognitive practice by using it as epistemic tool. Language was embedded in all cognitive practices; and the students used language to develop scientific sense making. This study found that their views about use of language clearly came from their epistemic orientation, in particular, their belief about How to Learn (L2) and belief about the Source of Knowing (G2). Although their beliefs about the nature of language differed slightly, they all believed that language should be used as a tool for helping students construct knowledge (epistemic tool).

The findings of this study suggest that teacher development should explicitly target a change in teacher epistemic orientation, rather than improving skills and attributes (Windschtl, 2002). In this study, the teachers' changes in epistemic orientations led to changes in the ways of using classroom resources and teaching strategies. To foster student engagement in constant negotiation, the teachers created cognitive conditions by managing the space and resources of the epistemic practices. Instead of controlling the whole direction and process of the practices, they designed and set up social interaction spaces (individual, small group, whole group), and resources (physical materials and time) of practices to create classroom dynamics. Resources include having sufficient time to develop knowledge (Collins, Brown, & Newman, 1989; Henningsen & Stein, 1997), having access to important materials and information (Roth, 1995), and having exposure to conceptual tools that guide reasoning (Lampert, 1990). According to the teachers, the resources and strategies currently used in their classrooms had been established through their previous knowledge and teaching experience. That is, they used the same resources and strategies but used them differently because their orientation shifted. This finding indicates that changes in epistemic orientation can affect how teachers use resources rather than what resources they use and design. Namely, they rearranged their knowledge bases regarding the resources. As they shifted in epistemic orientation, their knowledge bases for teaching science were rearranged.

Lastly, this study showed that teaching through science practice would not be well supported by prescribed curriculum materials. Although many studies have suggested inquiry-based instruction can be supported by curriculum materials (e.g., Borko & Putnam 1996; Crawford 2007), this study found that curriculum materials did not sufficiently guide teachers *how to teach*. The teachers relied on published curriculums and curriculum materials when they decided *what to teach*. Nevertheless, they presumed that the student-centered lessons could not be prescribed because instruction should be centered on students' ideas. Instead of planning lessons based on the published curriculums, they relied on their epistemic orientations when deciding how to teach. It seems that while curriculum and curriculum materials support and aid teachers to set conceptual goals for teaching science and to improve their knowledge of science content and topic-specific resources, they do not guide teachers how to help students improve learning. This does not mean that curriculum materials are less important, but views and use of curriculum and curriculum materials need to change.

Conceptualizing Learning-centered orientation

To take all of the findings together and develop a holistic conceptualization of EOTS, this study describes the three teachers' EOTS as learning-centered orientations. Although numerous lines of study have attempted to identify and define different types of conceptions of teaching, they did not explain how the teachers' different beliefs and thoughts shape these conceptions and how those are related to their teaching practices. Nevertheless, they did recognize the existence of at least two, broad, teaching orientations that range from focusing on a teacher/content-oriented approach to focusing on a student-centered/learning approach (Kember, 1997). Table 19 summarizes the key differences between a Teaching-centered orientation and a Learning-centered orientation, with respect to beliefs about knowledge and knowing, learning, teaching, and classroom practices. The table focuses on how each belief and practice identified in this study could fall under these two broad orientation categories.

Table 19. A Comparison of Teaching-Centered and Learning-Centered Orientation

	Teaching-centered orientation	Learning-centered orientation
Beliefs about knowledge and knowing	• Knowledge transmission • No justification • Focus on domain-specific nature	• Knowledge construction • Evidence based justification • Focus on domain-general nature
Beliefs about learning	• Learning is passive knowledge acquisition process • Teachers control student learning and classroom knowledge. • Students receive knowledge from teachers or authorities	• Learning is active knowledge construction and critique process • Students are in charge of their learning • Students hold ownership of their knowledge
Beliefs about teaching	• Teacher as primary source of knowledge • Teacher should deliver accurate knowledge to students.	• Teacher as classroom manager • Teacher should create learning environment where students are engaged in construction and critique.
Teacher practice	• Teacher-centered approach ➢ Mastery of knowledge and procedures ➢ Instruction centered on a correct answer ➢ Content-focused ➢ Creating a passive learning environment where students receive knowledge from teachers ➢ Language used as representational structure ➢ Group works are not valued	• Student-centered approach ➢ Cycle of negotiation (construction and critique) ➢ Instruction centered on student-oriented ideas ➢ Creating an active learning environment where students develop their own understanding ➢ Language used as epistemic/learning tool ➢ Different modes of group works are valued (for creating private and public negotiation spaces)

This study demonstrated that the teachers shifted in their beliefs and practices from Teacher/Teaching-centered to Student/Learning-centered and the essential elements of EOTS were explicitly and implicitly reflected in student-centered instructional practices of the three teachers. In addition, it revealed that student/learning-centered teaching reflected a more sophisticated level of epistemological beliefs, and beliefs about learning and teaching and all these beliefs aligned strongly with each other. Interestingly, while the teachers in this study held distinguishable domain-general and domain-specific epistemological beliefs, these were fundamentally aligned with each other in their belief systems. To put it more concretely, the teachers paid close attention to the domain-general nature of knowledge and knowing when conceptualizing teaching, rather than the domain-specific nature, emphasizing that all disciplinary knowledge is fundamentally developed in the same way.

Implications for Teacher Education

I believe that the model of EOTS developed through this study can serve as a conceptual framework to design a teacher education or professional development program that support teachers shift their beliefs and practices. This study suggests teachers will not use their knowledge, skills, and resources in appropriate ways that foster students' engagements in their own learning process unless they change their epistemic orientation. Thus, teacher educators need to think about how essential features of EOTS can be addressed in teacher-education programs. Based on the findings of this study, I suggest several implications for both in-service and preservice teacher education programs.

First, in-service professional development programs should prioritize beliefs about learning, in particular, beliefs about how students learn and beliefs about the control of learning. This is more important than other knowledge, skills, and attributes because it will help teachers shift their instruction from a teacher-centered to a student-centered approach. Therefore, professional development and teacher education programs should include in-depth discussions on how students learn, which could allow teachers to be aware of their thoughts and begin to change or reconstruct their beliefs and thoughts about student learning. The discussion should be reflective and interactive in nature. As students do, teachers also make sense of an idea by interacting with others, making connections between different ideas and engaging in their own reasoning process. Hence, the substantial learning opportunities where teachers can share their ideas and thoughts, listen others' ideas, challenge each other and build meaning together as a group should be included.

These learning opportunities can be supported by in-depth discussion sessions in a professional development program or in their school buildings. Although it was the beyond the scope of this study, professional learning communities helped the teachers develop an understanding of how students learn. Research supports the value of a learning community of teachers sharing ideas about actual teaching experiences and developing a collective understanding of teaching (Smyth, 1989). Although a teacher community was not a part of the ABI

PDs, all three teachers in this study valued teacher collaboration inside schools and so created a learning community inside their school. By interacting with other teachers, they expanded their evidence base concerning student learning as well as they shared common goals and inquired into ways of addressing them together. Moreover, this in-depth and reflective discussion should be repeatedly included until teachers re-adjust their knowledge and skill bases to align with their shifted ideas about how students learn. Numerous studies on teacher change established the premise that professional development with sustained supports, over a period time, has a generally stronger impact on teaching (Lieberman, 1996; Richardson, 1994).

As teachers begin to understand how students learn, they need to be engaged in ample opportunities where they can learn and experience science practice as a learner. By engaging in these practices, they can see alignments between epistemological bases of general knowledge, scientific knowledge, learning, and teaching. This will also aid the teachers in understanding how they can incorporate different science practices. To design these opportunities for teachers, researchers and teacher educators must choose an approach that addresses both the epistemic nature of science and how students can develop a conceptual understanding of science. In particular, these practices should be designed to help teachers view science practices as constant cycle of scientific reasoning, rather than step-by-step activities. In this study, the SWH approach helped the teachers see how the epistemology of science can connect to student learning in science. By engaging in the SWH activities and implementing the approach in their classrooms, the teachers could make strong connections between the epistemological basis of practices and their beliefs about learning and teaching.

Another suggestion for in-service teacher education program is related to the use of curriculum resources. This study suggests that a professional development program must address how to use curriculum materials in ways that engage students in the learning process. When teachers adopt a new approach, they are often concerned with designing new curriculum materials. Like the teachers in this study changed the ways of using curriculum resources without replacing all resources, teachers need to learn how to use their old curriculum materials in a way that encourage students' engagement in science practice. Moreover, teacher educators also need to change their views on use of curriculum resources. Given that student-centered lessons cannot be prescribed; teacher educators should pay close attention to changing teacher orientation rather than designing or providing well-structured curriculum materials.

Along the same lines, the model of EOTS can be used to redesign preservice teacher education program. Preservice teachers come to teacher education programs with their own beliefs about learning and teaching that influence what and how they learn from teacher education program (Holt-Reynolds, 1992); hence, it is important to allow preservice teachers to discover their own beliefs and question them. In this sense, it is important to create a non-threatening and supportive learning environment, where all ideas are explored and valued. Bondy et al. (2007) advised that, "Instructors much carefully consider whether alternate perspectives are represented through readings, and not only supported but protected in class discussions (p.79)."

In addition, preservice teacher education courses should be shaped around ideas about how students learn science. Instead of introducing different methods and skills for teaching science, programs should target development of preservice teachers' epistemic orientation. To help them develop epistemic orientation, it is important to design instructions with a student-centered approach because teachers tend to teach the way they were taught. By engaging in student-centered practices as learner, they can understand how students learn by holding ownership. Moreover, conceptual understanding of science and epistemology of science should be addressed together, within a course. Namely, preservice teachers can get more benefits by learning science and science practice together, rather than learning them separately.

Implications for Future Research

There are several areas that researchers need to examine to advance our understanding of EOTS and practices. First of all, it is necessary to retest the dimensions of EOTS. To this end, the dimensions of the EOTS need to be retested in other contexts. This study was conducted at the elementary level. Given that secondary school science teachers are trained specifically for science teaching, the model of EOTS should be re-examined by closely investigating secondary science teachers' EOTS and practices. In particular, the domain-general and domain-specific nature of epistemological beliefs should be studied further. Although the teachers in this study focused on the general domain nature of knowledge development, secondary teachers could have different views.

In addition, the model of EOTS needs to be tested with novice teachers. Although this study purposefully selected three exemplary teachers who were expected to show alignment between their beliefs and practices, discrepancies between epistemic beliefs and epistemic underpinnings of their instructions and educational materials might be typical for novice teachers. Patrick and Pintrich (2001) suggested that novice teachers might experience conflicts between their own epistemic beliefs about a topic and their epistemic beliefs about teaching the same topic to their students. Therefore, further studies needed to examine the differences in EOTS and practices between experienced and novice teachers. This will provide insight into a more sophisticated conceptualization of the EOTS.

Moreover, the changes of teacher beliefs with regard to essential elements of EOTS need to be further examined. Although this study suggests some implications about teacher change based on the teachers' reflections of these changes, this might not be consistent with how the change actually occurred. In particular, research on teacher beliefs has repeatedly called for understanding the teacher beliefs and relationship between beliefs and actions, specifically through the use of multiple-year, longitudinal case studies (Kagan, 1992; Zeichner, 1999). The results of a longitudinal case study will provide better evidence for the nature of change in EOTS, and in turn, will guide revisions of the EOTS model.

Another area that requires future research is associated with the development of robust and reliable measures of EOTS and instructional practices for science practice. This study assessed teacher beliefs through interviews and observations. Although this study provides in-depth descriptions about teacher beliefs, generalization and application of the EOTS model were limited due to small sample sizes. To generate enough evidence to show the relationship between EOTS and instructional practices, large-scale surveys (for EOTS) and rubrics (for instructional practices) are needed. The large-scale surveys should address all essential features of the EOTS found in this study; and the rubrics should address critical features of instructional practices that foster students' engagement in science practices. Designing and developing reliable and valid measures to assess the essential elements of EOTS and the critical features of instructional practice will provide tools to understand the professional growth and development of science teachers. Through development of an instrument based on empirical studies, future work can raise teacher comprehension of the EOTS that shape their teaching action and classroom environments.

Summary

This chapter discussed the study findings around three themes: 1) critical features of the EOTS, 2) the relationship between the EOTS and three dimensional instructional practices, and 3) the conceptualization of learning-centered EOTS.

The findings suggested that several features of the EOTS that should be targeted in teacher education programs. The beliefs about learning, in particular How to Learn and Control of Learning, were critical for leading a paradigmatic change in epistemic orientation. Specifically, while the How to Learn was a core belief that influenced the change in the entire structure of the EOTS, the Control of Learning led to changes in connections between beliefs about teaching and beliefs about learning. Moreover, the alignment between four major beliefs, including beliefs about knowledge in general, knowledge in science, learning, and teaching, was important to strengthen the orientation to teaching science.

The findings regarding the relationship between the essential elements of EOTS and instructional practices demonstrated that the elements of EOTS mostly determine instructional practices related to how teachers helped students learn science. In particular, the teachers' instructions reflected how they believed students learn, how they come to know, and how scientific knowledge is developed. However, they relied on the published curriculum, their knowledge, and experience of teaching when determining what to teach. The teachers used language, group works, and resources to create epistemic conditions that fostered student learning. Specifically, the teachers used language as an epistemic tool that helped students construct and critique knowledge and used group work to create spaces for private and public negotiation. In sum, the changes in EOTS are mostly associated with the changes in instructions regarding how to teach.

This chapter also discussed several implications for teacher education and future research directions. Teacher education programs must address the ideas about learning and epistemic foundations of science practice. In addition, future research should be directed at re-examining the essential elements of EOTS and the relationship between the EOTS and instructional practices with diverse subjects, context, and methodologies.

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Appendix A. Interview Questions

Interview #1: Pre-Instruction Interview

Demographic Information

- ❑ How old are you? (20-29; 30-39; 40-49; 50+)
- ❑ How many years have you been teaching?
- ❑ What grades have you taught?
- ❑ What areas are you certified to teach?
- ❑ How many science content courses did you take at college level?
- ❑ How many PDs (Professional Developments) have you had related to teaching science? What were those?
- ❑ Tell me your memories about elementary school science

Epistemological Beliefs – Nature of Knowledge

- ❑ Do you believe that knowledge is changed with time? Why do you think that? (Chan and Elliot, 2002)
- ❑ Sometimes people talk about 'searching for truth'. What is your opinion about this?
- ❑ Do you feel comfortable in dealing with ambiguous situations?
- ❑ The best ideas are often the simplest. On the flipside, are the best ideas the most complex? What do you think? (Jacobson, 2010)

Epistemological Beliefs – Nature of Knowing

- ❑ Could you explain where your knowledge came from? Is your knowledge mainly coming from authorities or self-construction?
- ❑ Do you agree that the content of textbooks is in general correct and highly believable? (Chan & Elliot, 2002)
- ❑ Do you think what experts say or write is right? Do you question it? (Cheng et al., 2009)
- ❑ What are your views? In learning about something you really want to know, what is the role of an expert? (Brownlee, 2003)
- ❑ How can you justify your knowledge? (Feucht & Bendixen, 2010)
- ❑ How do you know when you know something? (Brownlee, 2003)
- ❑ Which of the following are the deciding factors in obtaining knowledge? Inborn/innate ability, effort, understanding, learning method and strategy. (Chan & Elliot, 2002) Do you believe that perseverance and hard work can overcome difficulties in learning? (Cheng et al., 2009)

Nature of learning

- ❑ When you are learning a subject, what percentage will you attribute to your innate ability and to your learning effort? Why do you think that?
- ❑ How do students learn? (Cronin-Jones, 1991)
- ❑ Can you give an example of how this looks in your classroom?

- In science class what is students' role in the learning process?
- How do you know when your students are learning?

  (Materials, Activities & Reflection – if teacher does not address this in previous questions)
- What type of materials and activities do you use to support learning in your classroom?
- How do you believe students learn science best? (Luft & Roehrig, 2007)

Interview #2: Pre-Instruction Interview

Nature of Teaching

- In science class what is your role in the learning process?
- How do you decide what to teach?
- Howe do you decide what to ask your students?
- In your opinion, what are the goals of teaching science? (Kang & Wallace, 2005)

Argument-Based Inquiry

- How would you define the inquiry?
- How would you define the Argument-based Inquiry approach?
- Do you believe that argument-based inquiry approach helps students to learn better in science?

- What role does evidence play in your classroom?
- What is the different between Inquiry and Argument-based Inquiry approach?

Epistemology of Science

- What is science? What makes science different from other disciplines of inquiry (e.g., religion, philosophy)?
- How would you define science as knowledge? Is there a difference between scientific knowledge and opinion?
- Sometimes people argue that 'scientists are searching for truth'. What do you think about this statement?
- Where does scientific knowledge come from? Who give the current generation of scientists the "new" knowledge?
- What is an experiment? Does the development of scientific knowledge require experiments? Is there a difference between experiment and research in science?
- What role does evidence play in science? Is there a difference between data and evidence?
- What is scientific argument? Is there a difference between argument and explanation?

- ❑ After scientists have developed a scientific theory (e.g. atomic theory, evolution theory), does the theory ever change? If you believe that scientific theories do change, why we bother to learn scientific theories.
- ❑ Is contents of science textbook believable? How certain are scientists about the knowledge in science textbooks?
- ❑ Scientists perform experiments/investigation when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?
- ❑ Scientists have formulated several different hypotheses to explain the extinction of dinosaurs. How are different conclusions possible if scientists have access to and use the same set of data to derive their conclusions?

Interview #3: Post-Interview (pre-VSR)

Warm-up

- ❑ What do you see as your teaching strengths?
- ❑ What areas do you feel are relatively weak in your teaching?
- ❑ What is your goal for teaching science?
- ❑ What was your goal for teaching this unit?
- ❑ How do you feel about the lessons you had for this unit?

- ❑ How many times did you teach this unit?

General Questions about Instruction

- ❑ Can you briefly describe the lessons you've had for teaching this unit?
- ❑ What kinds of things did you take into consideration in planning this unit?
- ❑ What are the most important concepts (ideas) for your students to understand by the end of the instruction of this unit? Why?
- ❑ What misconceptions or alternative ideas do you think 5th grade students might have about the big idea of this unit?
- ❑ Were there any misconceptions/difficulties you identified during the lessons that you haven't known before? If yes, how did you respond to challenge the misconceptions/difficulties? Did it work? Why do you think it worked?
- ❑ How did you know when your students have misconceptions/difficulties? What strategies/approaches did you use to understand students' understanding of the big idea?
- ❑ How did you know when your students understood a concept/an idea?
- ❑ Did you make any changes in the lessons differently from the lesson plan or from the lessons you had done before? Why?
- ❑ What were you looking for in students' talks (conversation) as evidence of their understanding of the big idea?

- I noticed that you were encouraging your students to make connections between Science and Mathematics. Why?
- Why did you ask your students to make decision on what they would do for their learning?
- It looked like you kept changing learning spaces. Why did you use different grouping (small group, whole group, pair work)?
- Why did you ask your students to move between talking and writing?
- Can you explain how your students develop scientific language throughout the unit?
- You kept reminding them to think about the big idea. Why?
- Sometimes you stopped the lesson and pointed out their lack of listening and thinking. Why? How did you decide when you had to give this kind of instruction?
- The directions of your classroom conversations seemed to be decided by your students. Why did you let them lead the conversation?
- How did you know when you had to jump into their conversations?
- How did you manage your students' conversation to have them focus on a big idea?
- How did you know what materials/resources you might need to prepare?
- How did you decide how much time you would spend on a practice?

Interview #4: Post-Instruction (VSR)

- ❑ Please briefly describe what you and your students are doing in this video.
- ❑ Purpose or goal of this practice: What were your students expected to do in this practice? Why did you think this practice was important to advance student learning?
- ❑ Creating learning environment: How did you help them engage in this practice? Why?
    - Language: Writing or Talking
    - Social: Individual work or Small group or Whole group
    - Resources: Time/Materials
- ❑ What were you looking for in this practice as evidence of your students' understanding of the big idea? Were there any students' misconceptions/difficulties you identified during this practice?
- ❑ How would you like to modify this practice?

Appendix B: Topic of the Eight Selected-Lessons

Lesson Selected	Steve	Janet	Wilson
L1	Discussing force and mass regarding launched and dropped bottles.	Discussing friction. Selecting big idea questions	Discussing how force affects motion.
L2	Discussing force and gravity, and what causes forces Outlining claims for the investigation.	Discussing air pressure and how it balances inside and outside of objects.	Discussing what they learned from the investigations related to the big idea.
L3	Finding evidence for what causes force in dropped and launched bottle experiment.	Discussing variables for building a successful rocket.	Discussing the definitions of force and motion.
L4	Discussing and writing evidence for what causes force	Discussing how gravity affects force and motion.	Discussing variables and planning ramp experiment.
L5	Group work on what causes force in dropped and launched bottles. Discussing momentum and gravity.	Researching and discussing force, Newton's second law, incorporated acceleration.	Preparing paper and water bottle rocket experiments.
L6	Discussing the results of catapult tests. Drawing of the forces acting on the components of the catapult.	Discussing the variable of rocket (e.g. fin size, location, and number) and how they will go about testing.	Designing paper rockets to learn about force.
L7	Discussing friction and how it affects motion.	Discussing different materials for testing rocket.	Discussing the results of the rocket experiments.
L8	Discussing the relationship between mass, matter, inertia, change in motion, and acceleration.	Discussing how to modify the previous tests. Making connecting between paper and bottle rocket.	Discussing the variables that influenced the results of tests.

Appendix C. Coding Framework for the Analysis of Teacher Talk

Categories	*Sub-categories*	**Code**	**Descriptions**
Type	*Question*	Q	Teacher asks questions
	Statement	St	Teacher provides statements
Nature	*Initiation question/statement*	Int	To start classroom discussions, introduce new topics, or elicit students' understandings related to concepts, events and situations yet to be addressed in the ongoing discussion.
	Epistemic question/statement	Epi	In response to students' previous contributions to classroom discourse for reactive purposes such as sustaining discussion on a particular topic, following up on ideas previously introduced by students, and requesting elaborations or clarifications from students
Function of Question /statement	*Pumping*	*PP*	To foster student talk (e.g. "what else?", "Okay")
	Reflective Toss	*RT*	To throw the responsibility of thinking back to the student
	Challenging students' idea	*CC*	To encourage student to reflect on and reconsider his answer if he gives an inappropriate response
	Displaying (recalling)	*DP*	To recall (with predetermined "right" answer)
	Comprehension check	*CC*	To check whether students have heard and/or understood his or her previous utterances(s), this type of question is frequent in traditional, teacher-centered classroom discourse, serving to ensure students in fact receive information or content that the teacher conveyed
	Confirmation	*CF*	To establish whether they heard and/or understood a student's previous utterance correctly. This type of teacher question tends to have a yes-or-no format and typically involves partial or

			complete repetition of a student's previous utterance with a rising intonation.
	Clarification	*CL*	Clarification requests are teacher questions that require students either to elaborate on or repeat information previously given in order to clarify the meaning of their previous utterances. This type of question implies the teacher has not heard or understood a student's previous oral contribution to classroom discourse.
	Providing explicit Instruction/Information	Ins-P	To provide information about the process
		Ins-I	To provide information about the Ideas