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Preservice Science Teachers’ Pedagogical Content Knowledge for Nature of Science and Nature of Scientific Inquiry: A Successful Case Study

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PRESERVICE SCIENCE TEACHERS' PEDAGOGICAL CONTENT KNOWLEDGE FOR NATURE OF SCIENCE AND NATURE OF SCIENTIFIC INQUIRY: A SUCCESSFUL CASE STUDY

by

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The purpose of this dissertation project is to explore preservice science teachers' development of pedagogical content knowledge (PCK) for targeted aspects of nature of science (NOS) and nature of scientific inquiry (NOSI). Through multiple data sources, it is examined how preservice science teachers' understanding of NOS and NOSI have changed over the program, and manifests itself in their classroom practice. This is an exploratory multiple case study of participants' experiences and developments during a teacher development program. Data is collected in the form of open-ended surveys, interviews, observations, lesson plans, video materials, and teaching documents. After all data is collected, two participants, Charlie and Rose, are purposefully selected among those who participated in this program in order to show a successful NOS and NOSI teaching practice. All data is analyzed in three stages. The first stage includes the analysis of the questionnaires, interviews, students' works, and classroom observations before the two-weeks teaching practicum in order to describe of the development of their views and schema of their PCK for NOS and NOSI. The second stage includes the analysis of two-

weeks teaching practicum. The data from preservice teachers' teaching videos, teaching reflections, and observations are analyzed in order to understand what and how they teach regarding NOS and NOSI. In the last stage, two analyses are compared for consistency/inconsistency to answer of how their PKC is represented in their teaching practice, and the factors mediate their teaching is compiled. Data analysis indicates Charlie begin the program with mixed views, while, Rose has better views of NOS and NOSI at the beginning of the program. During the program, both two preservice teachers improve their understandings of almost all of the NOS and NOSI aspects. Data analysis about development of Rose and Charlie's PCK for NOS/NOSI indicates at the beginning of the program, Rose has better ideas of teaching NOS and NOSI than Charlie. She has a clear plan and organization to teach specific NOS and NOSI aspects. She is aware of different teaching strategies and assessments techniques, and how to use those while teaching NOS and NOSI. On the other hand, Charlie has very general ideas and views of teaching science. At the end of the program, there is a huge improvement on both Rose and Charlie's understanding of PCK. For integrating their knowledge, and factors mediate their abilities and teaching experience, Rose and Charlie successfully integrate the components of their PCK to create learning opportunities for their students. They rely upon their knowledge of subject matter, representations, instructional strategies, assessment, and curriculum to create opportunities, which engage students in making and testing predictions as well as supporting claims and conclusions with evidence. Also, some additional factors such as, teacher self-efficacy, lesson planning, or general pedagogical knowledge have quite a few impacts on their teaching practicum.

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CHAPTER I

INTRODUCTION

Statement of the Problem

The development and understanding of pedagogical content knowledge (PCK) is a complex process identified by the content that is taught, the context in which includes the content, and the strategies and representations the teacher reflects on his/her teaching experiences. If preservice teachers are to be successful in creating classroom environments in which subject matter and pedagogy are integrated in a way that promotes students' learning, they must experience such learning environments themselves (Magnusson et al. 1999). Therefore, teacher preparation must be a place in which those possibilities are not only encouraged, but are seriously realized.

The primary goal for the current science education reform plan is to prepare and develop a society that is scientifically literate (AAAS, 1989, 1993; NRC, 1996), and who will be responsible for personal decisions that affect the local and global community (Bell, Lederman, & Abd-El-Khalick, 2000; Smith & Scharmann, 1999). Nature of Science (NOS) and Nature of Scientific Inquiry (NOSI) are considered a part of scientific literacy in science education reform. Reform documents such as the Benchmarks for Science Literacy (AAAS, 1993), Next Generation Science Standards (NGSS, 2013), and the National Science Teachers Association position statement on NOS (2000) suggest that teachers of all grade levels need to help students develop an informed understanding of NOS and NOSI as a component of developing scientific literacy. However, several studies have indicated that K-12 students are not acquiring the necessary understandings of NOS and NOSI outlined in these reform documents (Irzik & Nola, 2014; Lederman, 2007; McComas, 2004; Schwartz et al., 2008). Moreover, research has shown that for students to sufficiently learn NOS and NOSI that teachers must have an effective understanding of them and an understanding of how to teach these (i.e., Pedagogical Content Knowledge for NOS and NOSI teaching) (Abd-El-Khalick, Bell, & Lederman, 1998; Brickhouse, 1990; Faikhamta, 2012; Hanuscin, 2013; Hanuscin et al., 2009; Hanuscin et al., 2011; Schwartz & Lederman, 2002; Wahbeh & Abd-El-Khalick, 2014).

Shulman (1986) originally defined PCK as “subject matter knowledge for teaching” and as “the ways of representing and formulating a subject that make it comprehensible to others” (p.9). While there is still no universally accepted conceptualization of PCK (Abell, 2007; van Driel, Verloop, & de Vos, 1998), understanding what it entails, how it changes, and the factors involved in that process in relation to NOS and NOSI has the potential to inform the implementation of current science education reforms.

PCK for NOS and NOSI is complicated and interrelates multiple fields of knowledge (Schwartz & Lederman, 2002) and surfaces through multiple instructional dimensions (Bartholomew, Osborne, & Ratcliffe, 2002). Research has shown that preservice elementary teachers can improve their understandings of NOS and NOSI through appropriate instruction (Abd-El-Khalick & Lederman, 2000; Abd- El- Khalick et al., 1998; Akerson et al., 2000; Bell et al., 2000; Eichenger, Abell & Dagher, 1997; Khishfe & Abd-El-Khalick, 2002; McComas et al., 1998; Rudolph, 2000; Schwartz et al., 2004), and in some cases transfer their understandings to classroom instruction with support (Hanuscin et al., 2011; Nilsson, 2008; Zembal-Saul et al., 2002). However, the kinds of support required aiding new teachers in teaching NOS and NOSI may not be possible to achieve for each teacher. A growing effort to help science teachers develop their understanding of NOS and NOSI, and related teaching practices has been an ongoing challenge in science teacher education (Lederman, 2007). Therefore, there is a gap to explore various strategies for helping teachers (both pre-service and in-service) to not only learn about NOS and NOSI for themselves, but to learn how to teach them to students (Lederman, 2007). The notion behind this view is that familiarity with either general pedagogies or an understanding of the subject alone is not enough for teaching NOS and NOSI. Rather, pedagogy must be blended with content. Since PCK has been described as the hallmark of good teaching practice in the disciplines (Berry et al. 2008) and represents an important concept in defining the characteristics of good teaching (Magnusson et al. 1999), it is appropriate to think of it in the context of teaching NOS and NOSI. It is reflected in teachers' understanding of which concepts of NOS and NOSI are to be taught, the selection of appropriate instructional materials, and the use of pedagogical tools such as metaphor and analogy to help students interpret NOS and NOSI (Haunscin et al. 2011). Unfortunately, there is an absence of studies on developing preservice science teachers' understanding of NOS and NOSI and strategies for teaching them within a PCK framework. Additionally, Loughran et al. (2012) identified that while much of the research on PCK has been on how to evaluate it; another major gap in today's research on PCK is how an understanding of PCK is directly correlated to enhancing science-teaching practice (p. 11). Within the context of developing PCK for NOS and NOSI, this study seeks to fill the above gaps by not only measuring the changes that occurred in science teachers' PCK for NOS and NOSI over a time period, but also how those changes are translated into their actual practices by identifying the essential elements of teacher professional development that led to improved science teachers' practices of NOS and NOSI.

Purpose of the Study

Given PCK usually develops as a result of extensive and extended experiences teaching a specific topic and that teaching experience is one of several variables shown to mediate and constrain the translation of teachers' views of NOS and NOSI into their teaching practice (Abd- El-Khalick et al., 1998), there is a need to focus on preserice science teachers who have successfully translated their views of NOS and NOSI into the practice. The purpose of this dissertation project is to explore preservice science teachers' development of pedagogical content knowledge for targeted aspects of NOS and NOSI in a 13-month ExpERTS program. Through multiple data sources, it is examined how preservice science teachers' understanding of NOS/NOSI and pedagogical knowledge have changed over the program, and manifests itself in their classroom practice. The overarching research questions guiding this work include the following:

Research Questions

1) How does content knowledge of NOS and NOSI develop over time for preservice teachers during the ExpeRTS program?
2) How does pedagogical content knowledge describe for preservice teachers during a teacher development program?
3) What factors mediate preservice teachers' abilities and teaching experiences to enact their PCK for NOS and NOSI?

Theoretical Framework

This study is utilized Magnusson et al.'s (1999) model of PCK (see Fig. 1) as the framework with which to understand preservice science teachers' development of PCK for targeted aspects of NOS and NOSI and implement it in their classroom practices. According to Magnusson et al. (1999), PCK includes: (a) orientations toward science teaching, (b) knowledge and beliefs about science curriculum, (c) knowledge and beliefs about students' understanding of specific science topics, (d) knowledge and beliefs about assessment in science, and (e) knowledge and beliefs about instructional strategies for teaching science (Explanations of each component of PCK is provided in Chapter II).

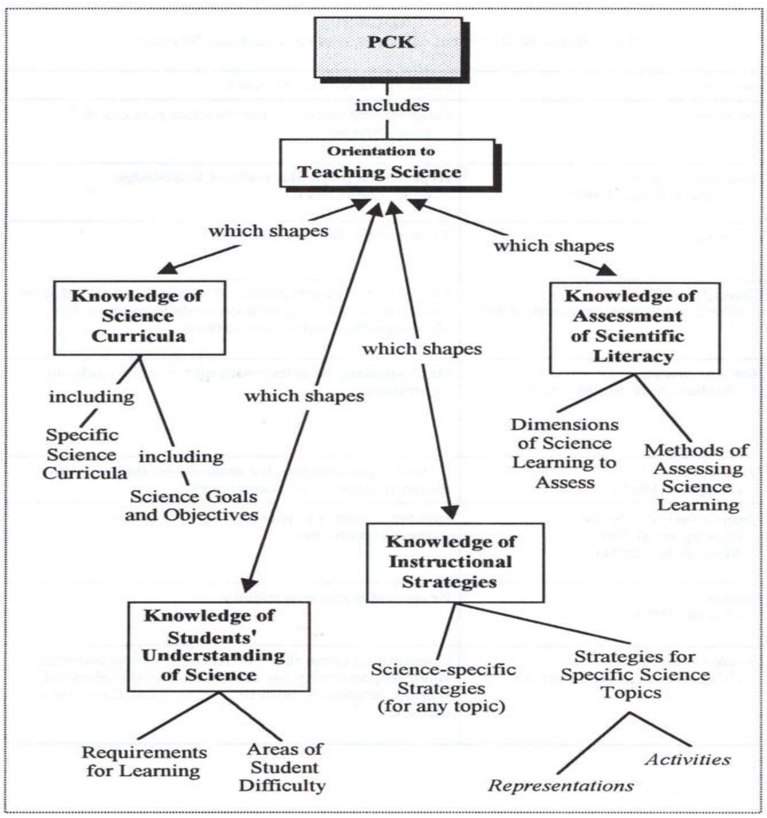

Figure 1. Magnusson et al.'s PCK component model for science (1999, p. 99)

Importantly, as emphasized by Abell (2007), however, while the discrete components of PCK in the model of Magnusson et al. (1999) can serve as useful tools for researchers, PCK is more than the sum of its parts. Thus, this study also seeks to examine the new possible components of PCK and the interplay between the components of it as teachers enact NOS and NOSI instruction. However, this study is still utilized Magnusson et al.'s (1999) model of PCK as the framework with which to understand how teachers understand the targeted aspects of NOS and NOSI and implement them in their classroom practices. Magnusson and his colleagues (1999) construct a PCK component model for science teaching, which contains both conception of teaching purposes and knowledge of evaluation. One of the contributions of this model is that it further specifies the PCK components, which makes the framework clearer and more easily applied to the studies on PCK.

Experiencing Research for Teaching Science (ExpeRTS) theoretical model of teacher professional development is also used to guide the design, data collection and analysis of this study. This model consists of 3 key components: (1) a mentored and authentic science research experience, (2) support and instruction for translating the experience into teaching practice, and (3) mentored teaching practice (See Fig 2). The details of the ExpeRTS program are explained in Chapter III.

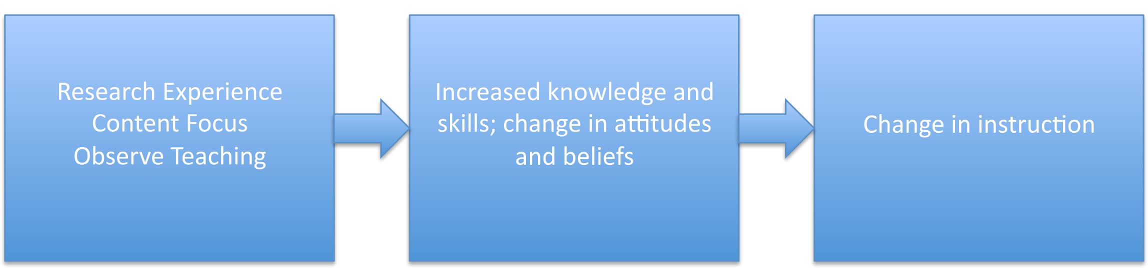

Figure 2. Theoretical Model of ExpeRTS Program

Although, there is an acceptable level of generality regarding NOS and NOSI that is accessible to K-12 students and relevant to their daily lives, it is important to note that the aspects of NOS and NOSI mentioned below are not meant as a comprehensive listing, there are other aspects that some researchers or reform documents include or delete (Abd-Khalick, Bell, & Lederman, 1998; Irzik & Nola, 2011; McComas, 2004; NGSS, 2013; Osborne et al., 2003; Schwartz et al., 2008). Any of these lists that consider what students can learn, in addition to a consideration of the characteristics of scientific knowledge, are of equal validity. Again, there is no definitive listing of the aspects of NOS and NOSI. The primary purpose here is not to emphasize one listing of aspects versus another, but to provide a framework of this dissertation.

The phrase "nature of science" can be difficult to define. No consensus presently exists among philosophers of science, historians of science, scientists, and science educators on a specific definition for NOS, but it typically refers to the epistemology of science, science as a way of knowing, the role of scientists, and the values and beliefs inherent to the development of scientific knowledge (Lederman, 1992). More specifically, NOS is studied by people to understand what science is, how it works, the epistemological and ontological foundations of science, how scientists interact socially, and the reciprocal role between science and society (Clough, 2006).

On the other hand, nature of scientific inquiry (NOSI) refers to the combination of general science process skills with traditional science content, creativity, and critical thinking to develop scientific knowledge (Lederman, 2009). Although scientific inquiry is closely associated with process skills such as observing, predicting, and collecting and analyzing data, it also includes content knowledge, scientific reasoning, and critical thinking to extend the current base of scientific knowledge.

Significance of the Study

This study adds to the growing body of literature on science teachers' PCK for NOS and NOSI. It provides a description of how PCK for NOS and NOSI is developed over time for preservice teachers during the 13-month program. It is significantly important to represent the journey of preservice teachers' development of their PCK for NOS and NOSI during the program. This study also represents how, to what extent, preservice teachers translate their understanding of PCK for NOS and NOSI into the practice. In addition, this study provides potential factors that mediate preservice teachers' abilities and teaching practices to enact their PCK for NOS and NOSI in the classroom. It may help add to the discussion of the potential models of PCK for NOS and NOSI and their usefulness in understanding teaching practice. If there can be understood what PCK for NOS and NOSI teachers have, what they use, and what PCK they are not using, there may be able to helped them find ways around these barriers. Also, if there can be understood how/what PCK effective teachers are using, the science education community might be able to be found the ways to help novice and experienced teachers improve their effectiveness by designing more relevant and useful learning experiences for NOS and NOSI. This study adds to our understanding of how preservice teachers use PCK to make daily decisions in their classrooms and design learning experiences for students. This research also attempts to help teacher educators and other educational reformists looking to improve science teaching for novice and experienced teachers.

CHAPTER II

LITERATURE REVIEW

The primary goal for the current science education reform plan is to prepare, and develop a society that is scientifically literate (AAAS, 1989, 1993; NRC, 1996), and that will be responsible for personal decisions that affect the local and global community (Bell, Lederman & Abd-El- Khlick, 2000; Smith & Scharmann, 1999). Not all science educators agree to the meaning of the term "scientific literacy". In addition, science reform outcomes are vague and often difficult to interpret (DeBoer, 2000). The National Science Education Standards (NRC, 1996) define evidence of scientific literacy as: (a) ask, find or determine answers to questions derived from curiosity about everyday experiences; (b) describe, explain and predict natural phenomenon; and (c) express positions that are scientifically and technologically informed. Abd-El-Khalick, Bell, and Lederman (1998) describe a scientifically literate individual as one who can make informed decisions within a science/technology context by drawing upon their rich scientific knowledge and understanding the concepts, principles, theories, and processes of science. There is no one, short, simple definition for scientific literacy. However, all aspects of scientific literacy expressed so far fit into three categories. In order to be scientifically literate, an individual (a) must have informed understandings of NOS, (b) understand the practices of scientific inquiry, and (c) have science content knowledge (AAAS, 1990; AAAS, 1993; NRC, 1996; NGSS, 2013).

PCK has become a central focus for this dissertation of how to teach particular content (NOS and NOSI for this study) to particular students at a particular point in time (Abell, 2007; Berry et al. 2008; Nilsson & Loughran 2012). PCK was firstly presented by

Shulman (1986), and his work forms the knowledge base for research on PCK. In his view, PCK is characterized as content knowledge that is related to its “teachability”. It includes “the way of representing and formulating the subject that make it comprehensible to others” and “an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons” (Shulman 1986, p. 9). After Shulman definition, researchers have adopted his ideas, but they have broadened and further studied different conceptualizations of PCK (Berry et al. 2008; Grossman 1990; Magnusson et al. 1999; Park & Oliver 2008). Although there are several knowledge components (Magnusson, Krajcik, & Borko, 1999) that inform the development of one‘s PCK (e.g., knowledge of learners of science, knowledge of instructional strategies, knowledge of curriculum, and knowledge of assessment), there are other factors that impact on or influence to teachers’ process information related to each of these knowledge components. These factors include teachers’ understandings of the subject matter, general pedagogical knowledge, and supports and limitations of the teaching context (Abell, 2007).

Conceptualizing NOS translates to exploring a way of knowing, or the values and beliefs inherent to scientific knowledge and its development (Lederman, 2007). The Next Generation Science Standards (Achieve, Inc., 2013) addresses NOS explicitly and provides guidance as to how NOS aspects are connected to science and engineering practices as well as crosscutting concepts. Within the research literature the following seven aspects are identified as key components of NOS that are attainable by K-12 students and are non-controversial as aspects of NOS. The aspects include that scientific knowledge; (a) is tentative (subject to change), yet robust because it is; (b) empirically based (based on and/or derived from observations of the natural world); (c) is the product of human imagination and creativity (involves the invention of explanation); (d) is influenced by current scientific perspectives as well as personal subjectivity due to scientists' values, knowledge, and prior experiences (theory-laden); (e) involves both observation and inference; (f) there are social and cultural views embedded in one's interpretations; and (f) includes the functional difference and relative status between scientific theories and laws. The details of the aspects and why they are important will be explained later chapters.

Like NOS, the meaning of "nature of scientific inquiry" has been debated for decades, and valid descriptions of what inquiry means for science education seem to vary as much as the methods of inquiry. Scientific inquiry refers to the characteristics of the processes through which scientific knowledge is developed, including the conventions of development, acceptance, and utility of scientific knowledge (Schwartz et al., 2008). There are some commonalities, which identify as agreed upon aspects of NOSI that are also relevant and important for science education. The general aspects of NOSI include: (1) scientific investigations all begin with a question and do not necessarily test a hypothesis; (2) there is no single set of steps followed in all investigations (i.e. there is no single scientific method); (3) inquiry procedures are guided by the question asked; (4) all scientists performing the same procedures may not get the same results; (5) inquiry procedures can influence results; (6) research conclusions must be consistent with the data collected; (7) scientific data are not the same as scientific evidence; and that (8) explanations are developed from a combination of collected data and what is already known (Lederman et al., 2014).

The literature review is organized in three sections. First section includes the development and different models of PCK. The second section includes understandings of NOS and NOSI. And, the last section includes PCK for NOS/SI. For the critical review, the empirical studies were selected from well-known and respected databases such as ERIC and Proquest, mostly in current years (Last 15 years have been searched carefully), which have been mostly referred by other researchers. The review by Lederman (1992, 2007) related to NOS, Abell (2007) related to PCK, and Gess-Newsome and Lederman's (1999) related to PCK and PCK for NOS, text also provided starting points in order to select papers for critical review. Also, the empirical articles were selected by considering the preservice science teachers as subjects because this study specifically focuses on preservice science teachers' PCK for NOS/SI.

Pedagogical Content Knowledge

The term pedagogical content knowledge (PCK) was introduced by Shulman (1986) as part of his conceptualization of a professional knowledge base needed for teaching. Shulman's (1986) definition of PCK includes not only knowledge about subject matter, but also knowledge about teaching strategies and about students themselves: who they are, their prior knowledge, and experiences to date. Shulman (1986) first proposed three categories of "content knowledge" for teachers:

- Subject-matter content knowledge;
- Subject-matter pedagogical knowledge; and
- Curricular knowledge. (p. 13)

Shulman emphasized the “amount and organization of knowledge per se in the mind of the teacher” (p. 13) related to subject matter content knowledge. For example, Shulman pointed out that a biology teacher’s knowledge of the content might rationally be expected to be equal to that of a non-teacher biologist. Shulman defined subject matter pedagogical knowledge as “the ways of representing and formulating the subject that make it comprehensible to others” (p. 13), that is, the analogies, illustrations, examples, explanations and ideas that a teacher uses in lessons. For the third category of his original list, Shulman exemplified “curricular knowledge” equates to a doctor’s knowledge of current techniques and/or treatments to relieve an illness: in teaching terms, current materials include textbooks, software, laboratory demonstrations and other techniques available to use in the classroom for effecting teaching. In his 1987 paper, Shulman refined his three categories into a more comprehensive list of seven;

- Content knowledge;
- General pedagogical knowledge, with special reference to those broad principles and strategies of classroom management and organization that appear to transcend subject matter;
- Curriculum knowledge, with particular grasp of the materials and programs that serve as ‘tools of the trade’ for teachers;
- Pedagogical content knowledge, that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding;
- Knowledge of learners and their characteristics;

- Knowledge of educational contexts, ranging from the workings of the group or classroom, the governance and financing of school districts, to the character of communities and cultures; and
- Knowledge of educational ends, purposes, and values, and their philosophical and historical grounds. (p. 8)

Shulman argues that although the other knowledge domains have their equivalents in different fields, PCK remains unique to teachers. In PCK, content and pedagogy are blended. The teacher combines his or her understanding about a topic within instructional strategies and additional knowledge to promote student learning. Shulman (1987) described PCK as:

> "... The capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students." (p. 15)

Teacher educators received Shulman's proposals enthusiastically. Subsequently, research effort has attempted to establish these categories of teacher knowledge as an all-embracing paradigm for teacher education. However, although Shulman's general views are widely accepted, many models of PCK have been proposed, as researchers have interpreted Shulman's ideas differently.

Models of Pedagogical Content Knowledge

Grossman's (1990) and Magnusson et al.'s (1999) models followed Shulman's definitions of PCK. They identified subject matter knowledge (SMK) as a distinct category and defining PCK as the special knowledge used by a teacher to transform his/her SMK to benefit students.

Grossman's (1990) model of pedagogical content knowledge have been widely used, studied, and developed by the other researchers (e.g., Magnusson, Krajcik, & Borko, 1999). Grossman's PCK model includes four central components:

- Knowledge of teaching goals, (including knowledge and beliefs about the objectives for teaching a specific subject matter);
- Knowledge of Curriculum, (including knowledge of curriculum materials for teaching a specific subject matter, and knowledge of horizontal and vertical curricula for a subject);
- Knowledge of student understanding, (including student' misconceptions, needs, and difficulties of particular topics); and
- Knowledge of representations and instructional strategies for teaching particular subject matter.

As compared to Shulman's (1987) definition, Grossman added, "knowledge of conceptions of purposes for teaching subject matter knowledge" on her PCK model. These components of Grossman's PCK model are demonstrated in Table 1.

Table 1

Components of Grossman's PCK Model (1990, p. 5)

PEDAGOGICAL CONTENT KNOWLEDGE		
Conceptions of Purpose for Teaching Subject Matter		
Knowledge of Students Understanding	Curricular Knowledge	Knowledge of Instructional Strategies

Tamir (1988) enlarged and extended Shulman's 1987 definition of PCK. His PCK model includes teachers' knowledge of evaluation, which is not included in Grossman's (1990) PCK model. As distinct from other PCK models, Tamir's (1988) emphasized the importance of declarative and procedural knowledge of PCK, which is identified under the category of "skill". (See Table 2)

Table 2

Components of Tamir's PCK Model (1988, p. 100)

	Knowledge	Skill
Student	Specific common conceptions and misconceptions in a given topic	How to diagnose a student conceptual difficulty in a given topic
Curriculum	The pre-requisite concepts needed for understanding photosynthesis	How to design an inquiry oriented laboratory lesson
Instruction (teaching and management)	A laboratory lesson consists of three phases: pre-lab discussion, performance, and post- laboratory discussion.	How to teach students to use microscope
Evaluation	The nature and composition of the Practical Tests Assessment Inventory	How to evaluate manipulation laboratory skills

Magnusson et al. (1999) developed and reconstructed Grossman's (1990) and Tamir's (1988) model of PCK. They generated a new PCK model for science teaching, including both knowledge of assessment and knowledge of teaching goals. As mentioned on Chapter I, one of the importance of Magnusson et al.'s PCK model is that it explicitly defines PCK components, which helps to future researchers to apply it on their studies about PCK. As presented under the section of theoretical framework on Chapter I, Figure 3 illustrates Magnusson et al.'s PCK model.

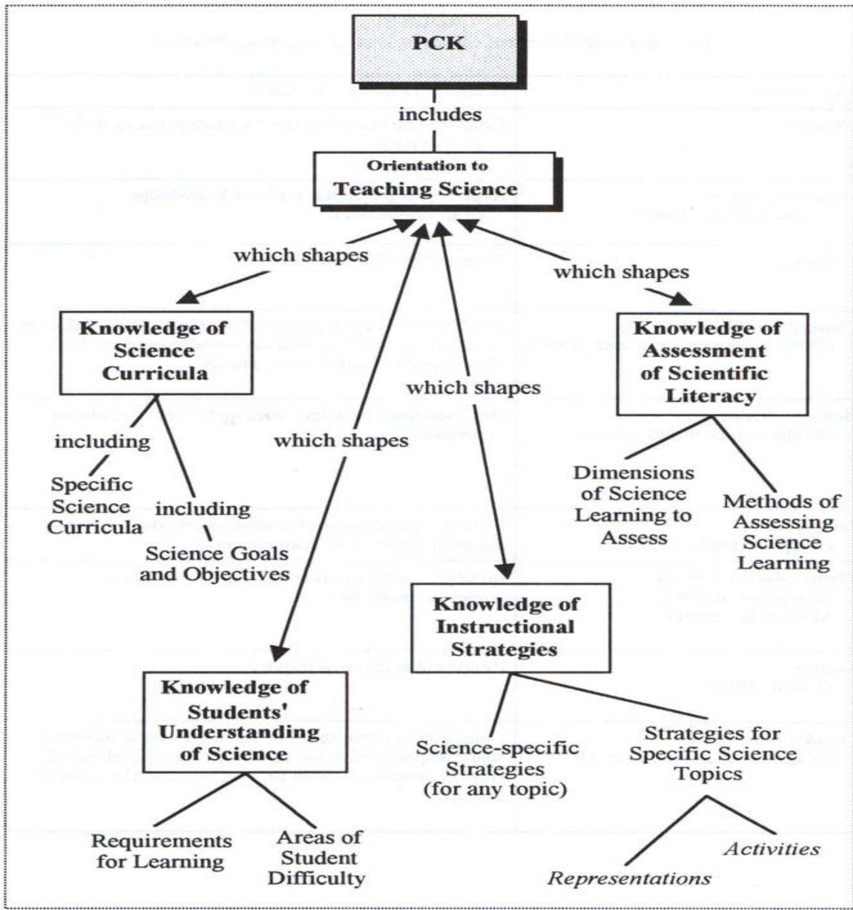

Figure 3. Magnusson et al.'s PCK component model for science (1999, p. 99)

Orientations to Teaching Science: This component refers to teachers' knowledge and beliefs about the purposes and goals for teaching science at different grade levels. Magnusson et al. (1999) explained that transformation of teacher knowledge from other knowledge areas of influence into PCK is not an obvious task but an intentional act in which teachers purposefully select to reestablish their understanding to translate into teaching a particular topic (Magnusson et al. 1999). Nine orientations toward teaching science identified by Magnusson et al. (1999): process, academic rigor, didactic, conceptual change, activity-driven, discovery, project-based science, inquiry, and guided inquiry.

Knowledge of Students' Understanding in Science: In order to employ PCK effectively, teachers must have knowledge about what students know about a topic and areas of likely difficulty. This component includes knowledge of students' conceptions of particular topics, learning difficulties, motivation, and diversity in ability, learning style, interest, developmental level, and need.

Knowledge of Science Curriculum: This component refers to teachers' knowledge of science curriculum materials available for teaching specific subject matter as well as about both the horizontal and vertical curricula for a particular subject (Grossman 1990). This component helps teachers to understand the importance of the particular topic relative to the curriculum as a whole. This knowledge enables teachers to explain core concepts, develop activities, and eliminate misconceptions judged to be peripheral to the targeted conceptual understandings.

Knowledge of Instructional Strategies and Representations for Teaching Science: This component includes two categories: subject-specific strategies and topic-specific strategies (Magnusson et al. 1999). Subject-specific strategies are general approaches to instruction that are consistent with the goals of science teaching in teachers' minds such as learning cycles, conceptual change strategies, and inquiry-oriented instruction. Topic-specific strategies refer to specific strategies that apply to teaching particular topics within a domain of science.

Knowledge of Assessment of Science Learning: Magnusson et al. (1999) emphasized the importance of teachers' knowledge of assessment. This component consists of teachers' knowledge of the assessments including dimensions of science learning, and knowledge of the methods by which that learning can be assessed (Tamir

1988). This component also includes knowledge of specific instruments, approaches, or activities for assessing student understandings or confusions.

Both Grossman's (1990) and Magnusson et al.'s (1999) PCK models suggested knowledge of purposes for teaching science, which is called "orientations" by Magnusson et al. (1999). These include discovery, conceptual change, process, didactic and inquiry. A teacher adopts one or more for different reasons: a 'didactic' orientation may imply fact transmission, while 'discovery' aims that students find out science concepts for themselves. Either will impact on instructional strategies, influencing PCK.

Grossman (1990) and Magnusson et al. (1999) also emphasized the importance of teachers' knowledge of curriculum. In addition, Magnusson et al. (1999) follow Tamir (1988), PCK model, which defined the importance of assessing in science teaching as comprising knowledge of the dimensions of science learning that are important to assess and knowledge of the methods by which learning can be assessed. Teachers must use assessment methods to find out what students have understood or confused.

Other researchers make use of PCK differently: Marks (1990), Fernández-Balboa & Stiehl (1995), and Koballa, Gräber, Coleman & Kemp (1999) include subject matter knowledge in their definitions of PCK.

Marks (1990) described PCK for teaching mathematics. He collected the data throughout interview including planning a lesson, critiquing classroom videotape, and diagnosing and remediating students' errors focusing on fifth-grade mathematics teaching. Marks defined PCK within four major category: (1) subject matter for instructional purposes, (2) students' understanding of the subject matter, (3) media for instruction in the subject matter, and (4) instructional processes for the subject matter.

Subcomponents of each are presented below in Figure 4.

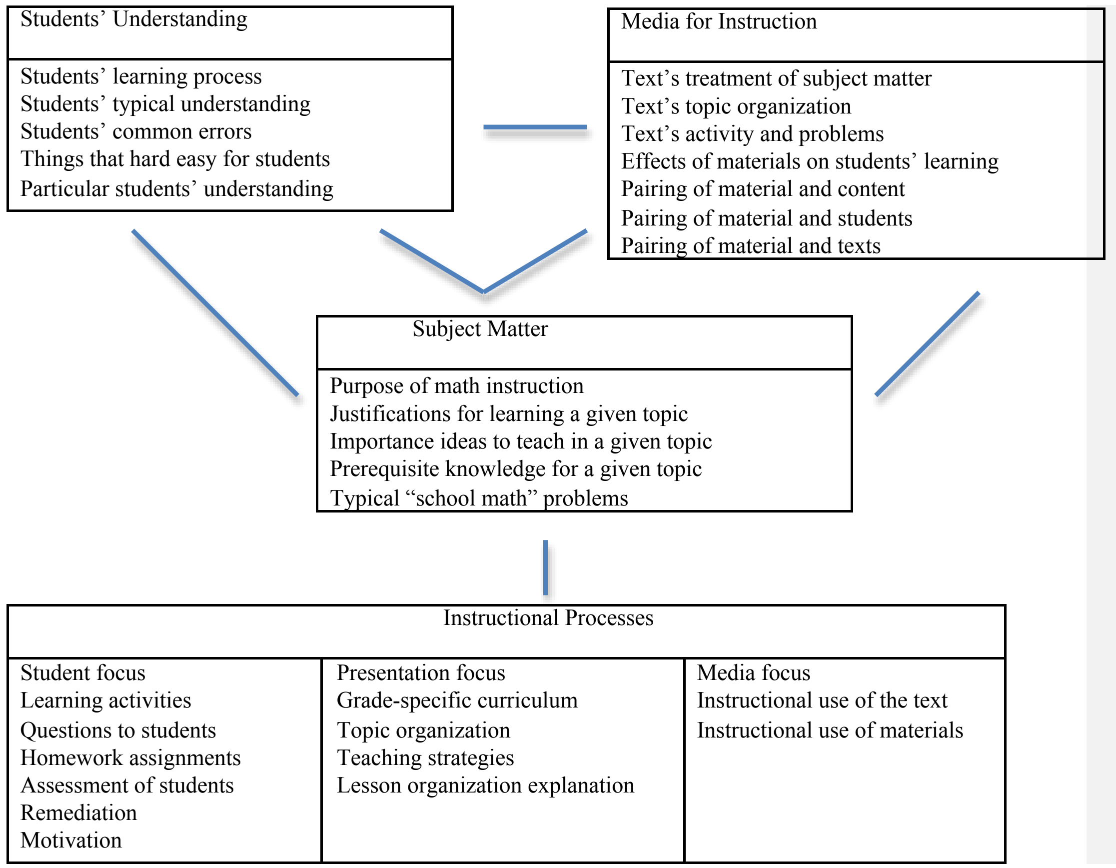

Figure 4. Marks's PCK model for teaching mathematic (1990, p. 5)

Fernández-Balboa & Stiehl (1995) argued similar evidence to Marks (1990). They suggested subject matter knowledge is one of the most important components in teaching practices. Their study showed that PCK comprises knowledge about subject matter; knowledge about students; instructional strategies; the teaching context and teaching purposes (p. 293). The authors emphasized that "contextual barriers" contribute to teaching, including solving the problems of large class sizes, specific time limits, lacking of available materials, and students' behaviors.

Gess-Newsome (1999) discussed different PCK models, which distinguished whether subject matter knowledge is separate from PCK or not. Gess-Newsome (1999) clearly presented the differences between ‘transformative’ and ‘integrative’ PCK models. Integrative model is indicated that PCK is not a separate knowledge domain. It includes comprising subject matter knowledge, pedagogy and context. On the other hand, transformative model is explained with subject matter, pedagogical and contextual knowledge for the goals of teaching students are shaped and transformed. In other words, in a transformative model, subject matter knowledge is a separate component, and teachers use their SMK for making PCK.

Shulman’s original definitions, Grossman (1990) and Magnusson et al. (1999) PCK models are transformative. These researchers argued that PCK involves the combinations of knowledge components in order to create PCK. The other models fit Gess-Newsome’s (1999) integrative model clarification. An integrative model includes components that represent knowledge of general teaching, teachers’ skills and abilities, classroom management, potential of learning environment and other factors.

Empirical Studies of Science Teachers’ PCK and Their Impacts on Instruction

After a brief summary of the development and different models of PCK in science education, three empirical studies about science teachers’ PCK and their impacts on instruction are critically reviewed.

Park and Oliver (2008) tried to examine the construct of PCK based on their empirical study with experienced high school teachers. The authors clearly showed the gap in the literature and the purpose of the study. They argued that explicitly using PCK has been difficult to describe a clear picture not only of how to build a framework of PCK development in teachers but also of how to assess teachers’ development of PCK. With this study, they assumed to gain better understanding of PCK and further facilitate communication among educational researchers, teacher educators, and teachers by eliciting agreement about the definition of understood concept.

The authors identified and focused on five components of PCK for science teaching mainly drawn from the work of Grossman (1990), Tamir (1988), and Magnusson et al. (1999): (a) orientations to science teaching, (b) knowledge of students' understanding in science, (c) Knowledge of science curriculum, (d) knowledge of instructional strategies and representations for teaching science, and (e) Knowledge of assessment of science learning. This study was a multiple case study grounded in a social constructivist framework of three experienced chemistry teachers. Data were collected from multiple sources including classroom observations, semi-structured interviews, lesson plans, teachers' written reflections, students' work samples, and researchers' field notes. The authors observed three subject matter units for each teacher using a non-participant observation method. All data were analyzed through three different approaches: (a) constant comparative method, (b) enumerative approach, and (c) in-depth analysis of explicit PCK. All these analysis approaches were clearly presented and fit their PCK study.

According the analysis of the data, the authors argued five elements of PCK. These components are: (a) knowledge-in-action and knowledge-on-action; (b) teacher efficacy; (c) students influencing; (d) teachers' understanding of students' misconceptions for planning, conducting instruction, and assessment; and (e) idiosyncratic PCK.

According to analysis, the authors presented PCK as a feature of knowledge in-action and knowledge on-action. Knowledge in-action is defined as knowledge developed and enacted during teaching through "reflection in action". In this respect, the development of PCK is an active and dynamic process. On the other hand, knowledge on-action means that knowledge elaborated and enacted through "reflection on-action". The teachers realized the need for extension or modification of their planning for teaching a particular topic. As a result, knowledge of in-action or on-action are not mutual, but rather influenced each other through reflection, either inside or outside classrooms. Authors argued that reflection-in-action and reflection-on-action significantly influence PCK.

The second feature is teacher efficacy as an affective component of PCK. The results showed that higher teacher efficacy impacts the establishment of overarching professional goals and manifest as a willingness to try new teaching strategies, which might support teachers' PCK and effectiveness.

The third feature is effect of students on PCK. Students' challenging questions to teachers influence teachers' PCK development. These questions frequently facilitated both deepening and broadening of the teachers' subject matter knowledge. Students' responses also motivated the teachers to expand or enrich their instructional repertoires as well as validate them. Overall, students played vital roles in determining the ways that PCK was shaped, developed, and validated.

Another factor is teachers' understandings of student misconceptions. The authors strongly argued that students' misconceptions are the major factor that shaped teachers' PCK. In this regard, the teachers focused on monitoring, redirecting, and challenging students' misconceptions since they perceived that misconceptions were a major barrier to further understanding. Therefore, teachers placed a great emphasis on students' misconceptions in both their planning and enacting of lessons. Overall, the authors stated that teachers' understanding of students' misconceptions impacted their decisions made throughout the entire teaching process from planning to assessment, which ultimately improved their PCK. As teachers developed better understanding of students' misconceptions, their PCK became more sophisticated.

The last factor is idiosyncrasy in the enactment of PCK. Although they found some common characteristics in three experienced teachers, four factors shaped the idiosyncrasy of these teachers' PCK. These are: (a) orientations to science teaching, (b) characteristics of students, (c) teaching experiences, and (d) personal characteristics. The explanation of these idiosyncratic characteristics illustrates how teaching can be a complex cognitive activity, as well as being highly context and topic specific.

Overall, Park and Oliver (2008) presented six factors, which affect teachers' pedagogical content knowledge that was conceptually grounded in five components of PCK for science teaching (Grossman, 1990; Magnusson et al., 1999; Tamir, 1988). However, one new effective component of PCK, teacher efficacy, was emerged. The emergence of teacher efficacy, the qualification of idiosyncrasy, the importance of reflection, and the recognition of the significance of students' roles as units within PCK led to an evolutionary modification of the heuristic model of PCK as shown in Fig. 5. In this evolved model, the concept of PCK represents not only teachers' understanding of how to teach subject matter effectively, but also the enactment of their understanding. The authors recognized that this model of PCK is not necessarily a working model from which a prescription for teaching can emanate. But there are very important conceptual aspects of this model, which can serve as a conceptual tool for future research. The six components influence one another in an ongoing and contextually bound way. In order for effective teaching to occur, teachers integrate the components and enact them within a given context.

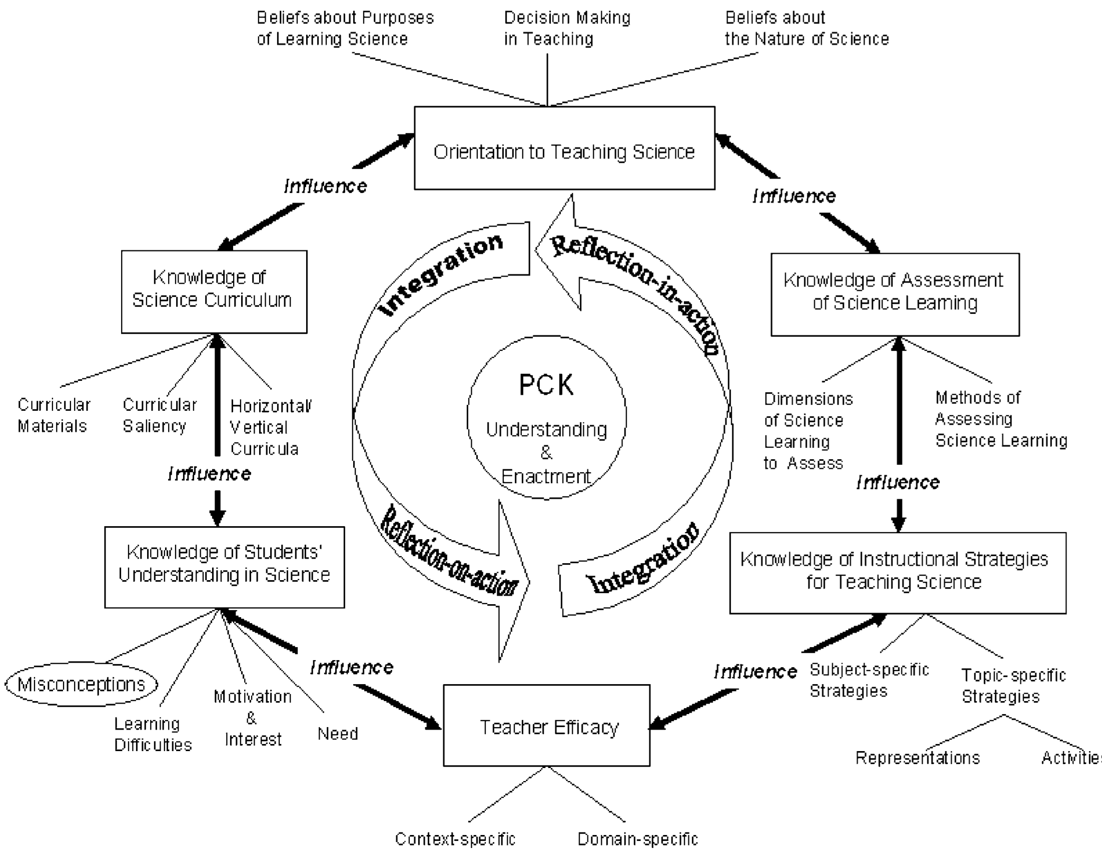

*Figure 5***.** Hexagon model of PCK for science teaching (Park and Oliver, 2008)

Nilsson and Loughran (2012) explored how a group of pre-service elementary science teachers came to understand the development of their PCK over the course of a semester's study in a science method course. The authors indicated that the problem was that elementary school teachers have limited science knowledge (Appleton, 2003; 2005), and their lack confidence in the adequacy of their own science knowledge influence their ability to do and learn science. Also, they indicated that examining teachers' PCK becomes more difficult because it is not directly observable but is manifested in performance in a specific teaching situation.

In this study, the authors captured science pedagogical content knowledge through Content Representations (CoRe) (see, Appendix E), which was developed by Loughran et al. (2004; 2006). CoRe makes teachers think about teaching a science topic based on recognition of the 'big ideas' for that topic mapped against pedagogical prompts including: what students should learn about each big idea; why it is important for students to know these ideas; students' possible difficulties with learning the ideas; and, how these ideas fit in with the knowledge the teacher holds about that content. As such, working with a CoRe could be one way of helping pre-service science teachers conceptualize their professional learning and empower them to actively develop their professional knowledge of practice in a specific content area. Two research question were guided in their study:

1. How did participating pre-service elementary teachers' PCK develop (as reflected in their pre and post teaching CoRes on the topic of Air) over the semester?

2. How did working with CoRes influence participating pre-service elementary teachers' learning about science teaching?

Thirty-four elementary science teachers participated in their PCK study. They enrolled in a three-and-a half- year preservice elementary teacher education program. A CoRe methodology was used to support these preservice teachers in planning for and assessing their knowledge of teaching of a particular science topic.

PCK was introduced to them, at the beginning of the semester, as a conceptual tool that teachers used for planning, assessing, and the development of their professional knowledge and practice. All participants were provided a CoRe and the manner in which they worked with it such that it supported them in planning for and assessing their own learning about teaching elementary science through a focus on the development of their PCK. Through analysis of data from CoRe based methodology (modified and adapted for this study) to the teaching of the science topic of Air, participants showed their confidence in, and perceived meaningfulness of their learning about science teaching could be examined.

The pretest and posttest were analyzed by considering individual preservice teacher CoRes and changes between pre-CoRe and post-CoRe (including quantitatively assessment of confidence and meaningfulness changes) and the reasons for such changes. Also, the authors focused on preservice teacher reflections on the process of working with CoRes as a frame for learning about science teaching. With regard to elements of CoRe 1 (What you intend students to learn), 2 (Why it is important for students to learn), 7 (Teaching procedures used in teaching this idea) and 8 (Specific ways of ascertaining student understanding), the authors argued that participant teachers believe these as highly important, and their perceived confidence in responding is also strong. These four components of PCK could be seen as the foundation on which participants' initial understandings of knowledge of practice is based.

According to analysis, the CoRe was experienced by participant teachers as a holistic tool for mixing up the content and the pedagogy in a way that determined their knowledge about what was important and why in their teaching about a specific science topic. Participants seemed to recognize how conceptualizing a topic through "big ideas" shaped the way they thought about what they were teaching and why.

The authors stated that when preservice teachers are engaged in purposefully identifying, self-assessing and explicitly developing their knowledge of practice in specific content, their understanding and development of PCK is significantly enhanced.

As Park and Oliver (2008) reported teachers' PCK is to some degree distinctive (idiosyncratic). In order to improve of teachers' PCK within a given specific lesson, it requires a teacher to integrate different components of PCK and each teacher develops those components as a result of different experiences and knowledge. Also, authors noted that preservice teachers develop their knowledge of their students' learning needs and help their students to better understand a particular big idea with becoming more sophisticated. Therefore, by focusing teachers' attention on practice through a consideration of the CoRe methodology, the participant teachers successfully developed their knowledge and skills of teaching of a particular topic, and that might count a real implication for science teacher education. However, Kagan (1990) argued, the complexity of teachers' knowledge of teaching for a particular science topic, which cannot be measured by a single instrument. Particularly, he suggested that assessment of PCK requires a combination of approaches that can collect information about what teachers know, what they believe, what they do, and the reasons for their actions (Baxter & Lederman, 1999).

As Nilsson and Loughran (2012) argued, it is a common belief that developing teachers' learning of their knowledge and beliefs is inevitably a complex challenge. Thus, Nilsson (2014) aims to develop science teachers' PCK through their participation in a learning study. The author argued that PCK is the result of a transformation of knowledge from other domains, and teachers need to develop knowledge of all aspect of PCK, which stated in Magnusson et al. (1999). Nilsson also used Magnusson et al.'s model of PCK, which consists of five components: orientations toward science teaching; knowledge and beliefs about science teaching; knowledge of students' understanding of science; knowledge of assessment in science; and knowledge of instructional strategies.

As explained above, the aim of the study was developing science teachers' PCK through their participation in a learning study. So, the important question for this study is what a learning study is? Nilsson (2014) explained "a learning study is a collegial process in which teachers work together with a researcher to explore their own teaching activities in order to identify what is critical for their students' learning." Learning study is different from lesson study. Lesson study is a teaching strategy as a continuous process of changing students' ways of seeing, which is important to know in order to learn about specific issues. On the other hand, in a learning study, a researcher is also involved in the process. Thus, Nilsson (2014) conducted this study with three secondary science teachers who worked in a learning study together with a researcher in order to identify conditions for students' learning. An important feature of the learning study is to pay attention to how teachers' collective construction of professional knowledge is enacted by making a shift from professional developments (PD) to professional learning (PL). During the learning study, Nilsson began the data collection from pre- and post-tests with the students, video-recorded lessons and stimulated recall sessions in which the teachers and the researcher reflected on the lessons to analyze how the teachers developed their knowledge of their students' learning and the impact of that knowledge on their own teaching.

During 10 weeks, three secondary science teachers and a science education researcher (author) worked together in a learning study in which the object of learning was to understand the chemical concept of “ion and how ions are formed”. The students were in 8th grade and they had previously been taught about the atom and atomic structure, but not yet about the concept of this particular topic. All three teachers were experienced science teachers, had worked together for several years and had volunteered to participate in the project.

As a learning study process, which identified by the author, the three teachers were asked to identify an object of learning, which was often difficult for students to learn. Then, the students’ background knowledge and their existing (prior) conceptions were investigated with a pre-test. The teachers and the researcher analyzed the test results together in order to understand how students experience what is to be learned, which is critical in order to learn the specific object. The results of this analysis become a source of planning the first lesson. One teacher conducts the lesson (lesson 1), which is video-recorded. After the lesson the students are given a post-test in order to provide an insight into how the students’ understanding of the object of learning and its critical features is changed (or not) after the instruction. Again, the three teachers and the researcher analyzed the video-recorded lesson (lesson 1) together with the students’ pre- and post-test results in a stimulated recall session (Nilsson, 2008) in order to share their experiences of the lesson with a focus on evidence of student thinking and analysis of the teacher’s instruction. Nilsson (2008) explained the purpose of the stimulated recall session is to capture aspects within the lesson that make difference for students’ learning and further to improve the lesson and revise it. Then, in the next phase of the learning study the second teacher conducts the (revised) lesson with his/her class (lesson 2) and the same procedure follows, with an analysis of the lesson and the pre- and post-test results. Finally, the third teacher conducts the (again revised of revised) lesson with his/her class following the same procedure. In the learning study, the role of the researcher was to support the teachers during the project and to work together with the teachers in meetings and discussions to stimulate their reflection. All the planning and monitoring of teacher group meetings were tape-recorded and the three lessons in the learning study were video-recorded and followed by reflections through stimulated recall interviews.

The author analyzed all data in a number of steps. First, all of the video recordings from the planning meetings were analyzed in an initial attempt to search for illustrative examples of how the teachers reflected on the object of learning and how to approach it within their teaching. Second, the pre- and post-tests were analyzed to get an insight into how the students understood the intended learning objectives. Third, the stimulated recall interviews after the three lessons and the final group meeting were analyzed through content analysis in order to identify recurring themes of situations and experiences expressed in the teachers' reflections. In such a way, the primary mode of analysis was the development of categories from the raw data into a framework that captured the key themes of how the teachers developed components of PCK (based on the framework outlined by Magnusson et al., 1999) during the learning study cycle.

This study illustrated that teachers' participation in a learning study proved to be helpful in their considerations and realizing of science teaching. Research about the effects of a learning study supports students' learning increases from lessons 1 to 3.

However, an important result of this study indicated that for lesson 2, students' results decreased, something, which forced the teachers to re-manage their taken-for-granted assumptions and pedagogical decisions. Another aspect of this study is that teachers commonly attribute failure in student learning to the students' lack of ability or motivation, rather than to their own teaching. Participating in a learning study has a difficulty for shifting from more general aspects of pedagogy to content-specific aspects of teaching and learning. A final important result concerns the theoretical framing of variation theory in identifying teachers' development of PCK. In short, the fundamental attribute of the theory is that the kind of learning the author want to achieve requires discernment of critical aspects of what is characteristically called the object of learning. To discern something means to be able to differentiate among the various aspects of a phenomenon. The object of learning was science teachers' development of (components of) PCK. As the author and the literature about PCK already been noted, PCK is a complex phenomenon where components interact in very complex ways (i.e. Magnusson et al., 1999). The teachers' discernment of what was experienced as successful and less successful in the different lessons might provide guidance on how different components interact within a teaching situation. Variation theory thus has the potential to become a valuable source of principles for science teaching that are directly useful for both researching and developing teachers' PCK.

As a conclusion, this study points to the particular role of research-based learning in providing opportunity for teacher learning as a metacognitive lens through which to view the task of science teaching in the secondary classroom. During the learning study process the teachers developed their self-understanding in which they questioned their aims and objectives of teaching and taken-for-granted assumptions about science teaching and learning. Another key insight was to limit the learning object and thus discern the science “Big Idea” (Loughran et al., 2006; Nilsson, & Loughran, 2012) and develop an increased knowledge about the relationship between subject content, teaching and student learning. Those aspects are central to a teachers’ PCK. An important implication for this project is the importance of teacher professional learning as a collective process where teachers and researcher together explore students’ learning in relation to science teaching.

Overall, the author clearly described the research questions, the theoretical framework and focus for the study. As indicated above, Magnusson et al. (1999) model of PCK was used as an appropriate model for this study. However, she did not talk about why this model is the most appropriate model among the others (i.e. Grossmon, 1990). One of the best strengths of this study was conducting the research align with a learning study. Learning study is important because teachers work together with a researcher to explore their own teaching activities. As indicated in results, this method is very important and crucial for their students’ learning in specific science content. However, some important questions need to be asked: What organizational support and actions are needed to promote and sustain activities such as learning study that can enhance science teaching and learning? And how can existing school culture be changed in ways that support teachers’ engagement in innovative teaching practices that build on collaboration in order to improve teaching and to enhance student learning?

Nature of Science and Nature of Scientific Inquiry

The construct NOS and NOSI have been advocated as an important goal for students studying science for more than 100 years and has continued to be advocated as a critical educational outcome by various science education reform documents worldwide (e.g., Australia, Canada, Chine, New Zealand, South Africa, United Kingdom, and the United States, among others) (Lederman & Lederman, 2014). As tried to explained above, understanding NOS and NOSI are often defended as being a critical component of scientific literacy (Lederman & Lederman, 2004; NGSS, 2013). At this point, the question of “what is nature of science and nature of scientific inquiry” might be asked. The phrase ‘nature of science’ can be difficult to define. No consensus presently exists among philosophers of science, historians of science, scientists, and science educators on a specific definition for NOS, but it typically refers to the epistemology of science, science as a way of knowing, the role of scientists, and the values and beliefs inherent to the development of scientific knowledge (Lederman, 1992). More specifically, NOS is studied by people to understand what science is, how it works, the epistemological and ontological foundations of science, how scientists interact socially, and the reciprocal role between science and society (Clough, 2006).

On the other hand, nature of scientific inquiry (NOSI) refers to the combination of general science process skills with traditional science content, creativity, and critical thinking to develop scientific knowledge (Lederman, 2009). Although scientific inquiry is closely associated with process skills such as observing, predicting, and collecting and analyzing data, it also includes content knowledge, scientific reasoning, and critical thinking to extend the current base of scientific knowledge. The National Science Education Standards (NRC, 1996, p. 23) define inquiry as follows:

> "Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking and consideration of alternative explanations."

There is currently much debate regarding specific definitions of scientific inquiry (Bell, Blair, Crawford, & Lederman, 2003; Schwartz, et al., 2004). Inquiry definitions are incompatible; inquiry is described as a method of teaching science, a method of doing science, and a method of learning science (Lederman, 1998).

As pointed out above, the nature of scientific inquiry refers to the characteristics of the processes through which scientific knowledge is developed, including the conventions of development, acceptance, and utility of scientific knowledge (Lederman et al. 2014; Schwartz et al., 2012). In order to highlight the importance of understanding the nature of scientific inquiry, the NGSS (2013) emphasizes what students should know in relation to inquiry, rather than skills of inquiry.

Although, there is an acceptable level of generality regarding NOS and NOSI that is accessible to K-12 students and relevant to their daily lives, it is important to note that the aspects of NOS and NOSI mentioned below are not meant as a comprehensive listing, there are other aspects that some researchers or reform documents include or delete (Abd-Khalick, Bell, & Lederman, 1998; Irzik & Nola, 2011; McComas, 2004; NGSS, 2013; Osborne et al., 2003; Schwartz et al., 2008). Any of these lists that consider what students can learn, in addition to a consideration of the characteristics of scientific knowledge, are of equal validity. Again, there is no definitive listing of the aspects of NOS and NOSI. The primary purpose here is not to emphasize one listing of aspects versus another, but to provide a framework of this dissertation.

Among the characteristics of scientific knowledge corresponding to this level of generality for NOS are that: (a) scientific knowledge is tentative; or subject to revision based on new information or new perspectives; (b) science is based on empirical evidence produced through direct and indirect observation of the natural world; (c) imagination and creativity play a role in the development of scientific knowledge; (d) science involves both observation and inference; (e) science is influenced by scientists' values, knowledge, and prior experiences (personal subjectivity) as well as currently accepted scientific perspectives influence the collection and interpretation of empirical data (theory-laden observations and interpretations); (g) social and cultural context also play a role in the development of scientific knowledge; and (g) there is a distinction and a relationship between scientific theories and laws (Lederman, 1992; 2007). The explanations of each aspect of NOS are provided below. These aspects of NOS were chosen among others because these are widely used by researchers.

Tentativeness: Scientific knowledge is tentative but durable which means that science cannot prove anything because the problem of induction makes “proof” impossible, but scientific knowledge is still valuable and long lasting. All scientific knowledge is subject to change in light of new evidence and new ways of thinking even scientific laws change. Scientists continually test and challenge previous assumptions and findings. New ideas are often received with a degree of skepticism, especially if they are contrary to well-established scientific concepts. Thus, scientific knowledge might be changed, but it is still valuable to develop and improve existence knowledge (Lederman, 2007; Lederman et al., 2014).

Empirical Evidence: Scientific knowledge is heavily based upon empirical evidence, which refers to both quantitative and qualitative data. All scientific ideas must conform to observational or experimental data to be considered valid while some scientific concepts are highly theoretical in that they are derived primarily from logic and reasoning, ultimately (Lederman, 2007).

Observations and Inferences: Science involves more than the accumulation of countless observations rather, it is derived from a combination of observation and inference. Observation refers to using the five senses to gather information, often augmented with technology. When past experience is included into making a judgment based on an observation, it is an inference, which involves developing explanations from observations and often involves entities that are not directly observable (Lederman, 2007).

Scientific Theories and Laws: In science, a law is a succinct description of relationships or patterns in nature consistently observed in nature. Laws are often expressed in mathematical terms. A scientific theory is a well-supported explanation of natural phenomena. Scientific theories are broadly based concepts that make sense of a large body of observations and experimentation. Thus, theories and laws constitute two distinct types of knowledge. One can never change into the other. On the other hand, they are similar in they both have substantial supporting evidence and are widely accepted by scientists. Either can change in light of new evidence (Lederman, 2007).

Creativity and Imagination: Creativity is a source of innovation and inspiration in science. Scientists use creativity and imagination throughout their investigations. The development of scientific knowledge involves making observations of nature. Nonetheless, generating scientific knowledge also involves human imagination and creativity. Science, contrary to common belief, is not a lifeless, entirely rational, and orderly activity. Science involves the invention of explanations and theoretical entities, which requires a great deal of creativity on the part of scientists. This aspect of science, coupled with its inferential nature, entails that scientific entities such as atoms and species are functional theoretical models rather than faithful copies of reality (Lederman, 2007).

Subjectivity/Theory-Laden: Scientific knowledge is subjective and/or theory-laden. Scientists' theoretical commitments, beliefs, previous knowledge, training, experiences, and expectations actually influence their work. All these background factors form a mind-set that affects the problems scientists investigate and how they conduct their investigations, what they observe (and do not observe), and how they make sense of, or interpret their observations. It is this (sometimes collective) individuality or mindset that accounts for the role of subjectivity in the production of scientific knowledge. Observations (and investigations) are motivated and guided by, and acquire meaning in reference to, questions or problems. These questions or problems, in turn, are derived from within certain theoretical perspectives. Often, hypothesis or model testing serves as a guide to scientific investigations (Lederman, 2007).

Socio-Cultural Embeddedness: Science as a human enterprise is practiced in the context of a larger culture, and its practitioners (scientists) are the product of that culture. Science, it follows, affects and is affected by the various elements and intellectual spheres of the culture in which it is embedded. These elements include, but are not limited to, social fabric, power structures, politics, socioeconomic factors, philosophy, and religion (Lederman, 2007).

The commonalities are agreed upon aspects of NOSI that are also relevant and important for science education: a) Questions guide investigations, b) multiple methods of scientific investigations, c) multiple purposes of scientific investigations, d) justification of scientific knowledge, e) recognition and handling of anomalous data, f) sources, roles of, and distinctions between data and evidence, and g) community of practice (Schwartz, 2004; Schwartz et al. 2008). The explanations of NOSI aspects are provided below.

Scientific questions guide investigations: Scientific investigations involve asking and answering a question and comparing the answer with what scientists already know about the world" (NRC, 2000, pg. 20). Contrary to the common "step one" of the scientific method, all investigations do not begin with the statement of a hypothesis. Before hypothesizing or considering what information may be helpful to gain understanding, scientists must ask questions.

Multiple methods of scientific investigations: "Scientists use different kinds of investigations depending on the questions they are trying to answer" (NRC, 2000, p. 20). There is no single universal scientific method. Scientists usually do not walk through the method sequentially. Scientists employ a wide variety of approaches to generate scientific knowledge, including observation, inference, experimentation, and even chance discovery. Studies in which no experimentation is performed are also valid scientific studies, but do not follow the scientific method (Lederman, et al., 2014; Schwartz et al., 2008).

Multiple purposes of scientific investigations: In general, "scientists aim to build and revise theoretical models with unobservable mechanisms" (Chinn & Malhotra, 2002, p. 188). The questions scientists choose to pursue stem from many sources and can serve many purposes. Why scientists choose to investigate certain questions may relate to curiosity, social impact, economy, practicality, or any variety of other reasons. "Current scientific knowledge and understanding guide scientific investigations." (NRC, 2000, pg. 20). The work of scientists may help solve a socially-based situation (such as disease), may be necessary to develop desired technology, may improve human condition, or may advance basic understanding of our world.

Justification of scientific knowledge: Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories" (NRC, 2000, pg. 20). The processes of negotiating meaning and gaining consensus involve building justification for claims. Evidence, consistency, and recognition of alternatives are associated elements. Nonetheless, scientists who ask similar questions and follow similar procedures may validly make different conclusions. Further, scientists who examine the same data may justifiably come to different conclusions. As stated by a scientist in a study by Osborne et al. (2003) "'it is crucial to know that scientific data does not stand by itself, but can be variously interpreted' (PS1)" (p. 708).

Recognition and handling of anomalous data: Investigations are guided by current knowledge and theory, thus scientists have expectations. Recognizing when observations do not fit expectations is a critical part of progress in science. Anomalies spark more questions and drive further investigations. Authentic science involves a variety of approaches to handling anomalous information (Chinn & Brewer, 1993; 1998). These include rejection (error negates anomaly), ignoring the anomaly, inclusion without explanation, abeyance (set aside), acceptance with theory change, and reinterpretation of data, peripheral theory change.

Distinctions between data and evidence: Data and evidence serve different purposes and come from different sources. Data are observations scientists gather during the course of an investigation. They can take a variety of forms (e.g. numbers, descriptions, photographs, audio, physical samples, etc). Evidence is a product of data analysis and interpretation. Evidence is directly connected to a question and claim. How data are analyzed and interpreted depends on the questions being addressed and currently accepted practices.

Community of practice: Scientists review and ask questions about the results of others' work....Science advances through logical skepticism" (NRC, 2000, pg. 20). Scientific inquiry is embedded within a community. There are multiple communities within the broader community of science (Knorr-Cetina, 1999). Practices and standards for developing and accepting scientific knowledge are established within these communities. Communication and peer review impact what and how science progresses.

None of these aspects can be considered apart from the others. For example, tentativeness of scientific knowledge stems from the creation of that knowledge through empirical observation and inference. Each of these acts is influenced by the culture and society in which the science is practiced as well as by the theoretical framework and personal subjectivity of the scientist. As new data are considered and existing data reconsidered, inferences (again made within a particular context) may lead to changes in existing scientific knowledge.

Although scientific inquiry and NOS are not independent from one another, and overlap and interact in important ways, it is nonetheless important to distinguish the two. NOS embodies what makes science different from other disciplines such as history or religion. As previously defined, NOS refers to the characteristic of scientific knowledge that are necessarily derived from how the knowledge is developed. (Lederman, 2007). On the other hand, Lederman et al., (2014) define SI as "although closely related to science processes (practices), scientific inquiry (SI) extends beyond the mere development of process skills such as observing, inferring, classifying, predicting, measuring, questioning, interpreting and analyzing data. Scientific inquiry includes the traditional science processes, but also refers to the combining of these processes with scientific knowledge, scientific reasoning and critical thinking to develop scientific knowledge". This distinction is further supported by Next Generation Science Standards (NGSS; Achieve, Inc., 2013), which distinguishes between NOS and scientific practices.

Empirical Studies of Teaching NOS and NOSI

Numerous attempts have been undertaken to enhance learners' views of NOS and SI. These attempts can be categorized under two general approaches: implicit, and explicit/reflective. The following section presents illustrative examples of each of these approaches, and empirical studies of teaching and learning of NOSI and SI.

The implicit approach of teaching NOS refers to the use of hands-on inquiry-oriented activities and/or science process skills instruction to enhance students' conceptions of NOS even though lacking explicit references to NOS. Most of the 1960s and 1970s curricula, such as the Physical Science Study Curriculum (PSSC) and the Biological Sciences Curriculum Study (BSCS), adopted such an approach. However, research has consistently shown that the implicit approach was not effective in helping students develop informed NOS views (Abd-El-Khalcik & Lederman, 2000; Lederman, 2007). Indeed, Crumb (1965) and Trent (1965) reported that the inquiry-oriented PSSC curriculum was not more effective than a traditional textbook-centered curriculum in enhancing students' NOS views. Crumb's sample was composed of 1275 students from 29 rural and urban high schools, whereas Trent's sample consisted of 26 experimental and 26 control high schools. In both studies, no significant differences were found between experimental and comparison groups' NOS views as measured by the Test on Understanding Science (TOUS) (Klopfer & Cooley, 1961) even after Trent controlled for participants' prior science knowledge and mental ability.

Similarly, Jungwirth (1970) found that 693 10th graders from 25 schools taught using the BSCS Yellow Version did not achieve significantly better scores on the TOUS and Processes of Science Test (BSCS, 1962) than comparison students (215 students from seven schools) enrolled in more traditional high school biology programs. More recently, Meichtry (1992) investigated the effect of the BSCS program on middle school students' understandings of the developmental, testable, creative, and unified NOS. Scores on the Modified Nature of Scientific Knowledge Scale (MNSKS) (Meichtry, 1992) showed that the experimental group participants' understandings of the developmental and testable NOS decreased significantly relative to the comparison group students. Meichtry concluded that there is a need for ‘‘explicit representation of all aspects of the nature of science by the curriculum content taught and the instructional methodology used by teachers’’ (p. 405).

The ineffectiveness of the implicit approach in enhancing students' NOS views could be attributed to an underlying assumption: students would automatically develop better NOS conceptions as a by-product of engagement in science-based inquiry activities or science process skills instruction. Abd-El-Khalick and Lederman (2000) noted that this assumption is based on the view held by some science educators, which depicts learning about NOS to be an affective learning outcome. Alternatively, an understanding of NOS should be considered a cognitive learning outcome and should be taught explicitly rather than implicit process during the regular science activities.

The explicit/reflective approach advances that the goal of improving students' NOS views ‘‘should be planned for instead of being anticipated as a side effect or secondary product’’ of varying approaches to science teaching (Akindehin, 1988, p. 73). In the context of improving science teachers' NOS views, some advocates of the explicit approach used instruction specifically geared toward various NOS aspects (i.e. Billeh & Hasan, 1975), whereas others augmented such instruction with elements from history and philosophy of science (e.g., Ogunniyi, 1983). More recently, reflective elements have been given prominence within the explicit approach. Explicit/reflective NOS teaching does not mean direct instruction. It refers to explicit attention to NOS within the context of inquiry-oriented instruction, historical case studies, science stories, and any type of science instruction. Abd-El-Khalick (2001), Abd-El-Khalick, Bell, and Lederman (1998), and Akerson, Abd-El-Khalick, and Lederman (2000), used explicit and reflective activity-based instruction (Lederman & Abd-El-Khalick, 1998) to promote teachers' NOS views. In these latter studies, teachers were first explicitly introduced to certain NOS aspects and then provided multiple structured opportunities to reflect on these aspects in the context of the science-based activities in which they were engaged or science content they were learning to help them articulate their views of the target NOS aspects and develop coherent overarching NOS frameworks.

Evidence suggests that an explicit and reflective approach could substantially improve learners' NOS views. Examinations of the literature indicate that an explicit approach is relatively more effective than an implicit one in furthering science teachers' understandings of the scientific enterprise (Abd-El-Khalick & Lederman, 2000; Lederman, 2007). Simply put, an explicit/reflective approach emphasizes student awareness of certain NOS aspects in relation to the science-based activities in which they are engaged, and student reflection on these activities from within a framework comprising these NOS aspects.

The following section has five empirical studies that talk about the importance of explicit/reflective NOS and SI instruction versus implicit approach. The literature on NOS and SI teaching is consistently supportive of an explicit/reflective approach in association with science learning experiences (Abd-El-Khalick & Lederman, 2000; Lederman, 2007). These studies have explored the influence of explicit NOS teaching on pre-service teachers' views of NOS and SI (Abd- El- Khalick et al., 1998; Abd- El-Khalick & Lederman, 2000; Bell et al., 2000; Akerson et al., 2000; Khishfe and Abd-El-Khalick, 2002; and Schwartz et al., 2004).

Khishfe and Abd-El-Khalick (2002) compared the influence of explicit and implicit inquiry-oriented instruction on sixth graders' views of NOS. The study emphasized the tentative, empirical, inferential, and creative aspects of NOS. The authors support their focus on these aspects based on their inclusion of reform documents as relevant for sixth grade science instruction. The implicit approach to NOS instruction assumes that the learner will come to understand NOS as a by-product of engaging in inquiry-based activities. The explicit and reflective approach assumes understanding NOS is a cognitive learning outcome and must be planned for accordingly. The empirical literature cited in this study supports the effectiveness of the explicit and reflective approach over the implicit approach in advancing learners' NOS conceptions. The purpose of the present study was to explore the relative effectiveness of these two approaches on sixth grade students' NOS views.

Sixty-two sixth grade students enrolled in two class sections in a private school in Beirut, Lebanon, served as the sample for this study. The authors give no indication of how the students were divided into the sections. One section, 33 students, was the explicit group. The other section, 29 students, was the implicit group. The authors state equivalent achievement levels for the two groups. They administrated a six-item open-ended NOS questionnaire in a pre/post format. Validation procedures for the questionnaire included expert reviews and pilot testing. Eight students from each group were purposefully selected for interviews after both administrations, for a total of 32 student interviews. The interviews served to further validate the questionnaire by ensuring common interpretation of items and responses between respondents and researchers. Interviewees were chosen based on science achievement and gender, to allow for wide variance in types of responses. Different students were interviewed at the beginning and end of the intervention. The first author served as the teacher of both groups, administrated the questionnaire, and conducted the interviews. Given that she was the teacher, the students may have viewed the questionnaire and interviews as evaluative and in need of a “correct” answer. There is no indication by the authors of attempts to minimize students’’ concerns.

The teacher taught six inquiry-based activities that included five activities in physical science (atomic structure, mixtures, phase changes, heat and heat transfer, and combustion) and one activity in earth science (fossils). The teacher taught two, 50-minute science lesson per week to both groups, for the ten weeks of the intervention. Both groups experienced the same six activities using a guided inquiry model. Students worked pairs or groups of three. The teacher introduced the activity by posing a question or problem. The students then clarify their questions, make predictions, design data collection, defend their procedures to the whole class, collect data, organize and analyze data, and pool results with the class. Students then engaged in whole-class discussions to derive generalizations from the investigations. The teacher guided discussions to address the science content and science process skills.

The explicit group then received reflective NOS instruction wherein the teacher addressed aspects of NOS depicted in the different activities. The authors report that by the fourth activity, the students in the explicit group were able to initiate NOS discussions, rather than wait for the teacher to ask the guiding questions. Targeted NOS aspects relative to each activity were not reported. There is no indication that different aspects or perspectives of aspects were addressed based on the content area or investigation studied. The implicit group did not address NOS. To equalize instructional time, the implicit group continued discussion about content or process skills.

Classroom observations were conducted through videotaped sessions. The two authors reviewed the tapes to ensure the validity of the intervention. Given that both authors knew the categories of each group, their observations were somewhat biased. A blind observation of classroom instruction to determine the extent of explicit and implicit instruction and similarity of guided instruction during the activities would be preferred for validating the integrity of the purported intervention.

Data were first analyzed by the first author (the teacher), and a blind analysis conducted by the second author. They discussed results until consensus was reached. Pre- and post instruction profiles were generated for each participant. Profiles described participants' views of the four-targeted NOS aspects.

Results indicate pre-instruction NOS views were similar for both groups, with 85% demonstrating naïve views of tentativeness, creativity, empirical, and inferential NOS. Khishfe and Abd-El-Khalick present quotes and descriptions of participants pre-instruction views. The descriptions are categorized based on NOS aspects. The explicit group advanced in their conceptions of NOS more than the implicit group. Again, representative quotes and descriptions are presented. The implicit group showed gains in conceptions of the inferential NOS (7% initially to 18% post). The authors attribute this advance to the teacher's need to clarify observation and inference during discussions of science process skills. However, the 31% of the explicit group gained more informed views of the inferential NOS. overall gains for the explicit group included: 46% (tentative); 31% (observation vs. inference); 42% (empirical); and 31% (creative). The implicit group demonstrated a decrease in understanding of the creative NOS (7% initially to 4% post).

Khishfe and Abd-El-Khalick appropriately state that their findings indicate their explicit and reflective inquiry-oriented approach was more effective than the implicit approach. They also recognize the limited advancements in their participants. Less than 50% of the participants in the explicit group held informed views of the NOS aspects at the end of the intervention. There is much room for improvement. Understanding the creative NOS seemed difficult for this group of sixth graders. The authors suggest the difficulty in understanding NOS in general, as well as specific aspects of NOS, might be due to development constrains of 11-years olds. Furthermore, they suggest difficulties might arise due to general difficulties learners have with changing misconceptions in just 10 weeks of instruction. The researchers suggest a conceptual change approach with historical case studies might improve the effectiveness of the explicit instruction.

Finally, the authors suggest the context of the learning situation might impact learners' developing NOS conceptions. The science content that was more familiar with these participants was dinosaurs. The context of structure and matter was less familiar. Students had more difficulty relating NOS to the structure and matter context. It is not clear from the discussion whether the difficulty was encountered during the class discussions or whether the responses on the questionnaire were different for the dinosaur question and atomic structure question. If there was a difference in the classroom discussions, the difference might be due to the fact that the structure and matter lesson occurred early in the intervention and the fossil activity was the final activity. One would expect the students to be better able to relate NOS aspects to the fossil activity after having engaged in five previous similar focused discussions. Furthermore, it would be expected that the students' responses on the dinosaur and atomic structure questions could be similarly disparate. The authors do not raise this issue. So the question remains, is the difference in student ability to relate NOS within different contexts due to the subject matter itself, or due to the chronology of instructional experiences. They do recommend more investigation is needed into possible relationships between subject matter knowledge and conceptions of NOS.

In the article entitled "The nature of science and instructional practice: Making the unnatural natural," Abd-El-Khalick et al. (1998) propose to elucidate the relationship of pre-service teachers' views of (NOS) with their planning and student teaching. The participants of this study were fourteen pre-service science teachers, nine male and five female. Participants were enrolled in a fifth year master of arts in teaching (MAT) teacher preparation program in a rural, mid-sized state university. All participants had earned BS degrees and seven had earned MS degrees. The MAT program places emphasis on NOS, and its implications for teaching science in the classroom. In particular, pre-service teachers are explicitly taught several aspects of NOS using activities that can be employed with secondary level students. For this study, pre-service teachers directly experienced or discussed approximately fifteen different NOS activities. Some of NOS activities were content-embedded (e.g. the fossil activity), while others were generic (e.g. black box activity). These activities mainly referred to one or more aspects of NOS which included tentativeness, subjectivity, imagination and creativity, empirical base, observation and inferences, scientific theories and laws, and social and cultural embeddedness.

Data was collected during the entire year participants were enrolled in the MAT program. Seven item open-ended NOS questionnaire and follow-up interviews were used as primary data sources. This seven item instrument was used to assess pre-service teachers' views of the tentative, empirical, creative, and subjective nature of science; the role of social and cultural contexts in science; observation versus inference; and the functions and relationships of theories and laws. Follow-up interviews were conducted to validate participants' responses to the questionnaire. Other primary data sources included copies of participants' daily lesson plans, classroom videotapes, supervisors' weekly clinical observation notes, and each participant's portfolio. All these data sources were analyzed to document whether the pre-service teachers planed to teach or taught NOS explicitly. Three researchers independently analyzed each data source in order to understand whether the answers explicit or implicit which participants addressed NOS in their teaching plans until better than 90% agreement was achieved among the all three researchers. In this analysis, each participant was treated as a separate case. After the all data sources were analyzed, categories and factors were generated in order to organize the data.

The results were reported in three sections which including pre-service teachers' conceptions of NOS, their instructional practices related to NOS, and interaction between participants' NOS views and their beliefs about instructional outcomes. According to analysis of the responses to the open-ended questionnaire and other data sources, Abd-El-Khalick et al. (1998) stated that, in general, all participants emphasized that science is empirically based. In other words, they indicated that this aspect is essential in differentiating science from other disciplines of inquiry, such as religion and philosophy. Tentativeness was another aspect of NOS that was clearly identified by all participants. Participants believed that science is tentative which means it is subject to change by virtue of collecting new data. All participants recognized subjectivity and creativity are inherent to scientific knowledge. The participants also clearly emphasized the difference between data and evidence. However, the participants were less successful in describing their understanding of the relationship between scientific theories and laws. In addition, participants did not have an adequate understanding of the socially and culturally embedded NOS.

Based on the analysis of the planning for and teaching of NOS, the supervisors' field notes, and the pre-service teachers' videotaped lessons, Abd-El-Khalick et al. (1998) identified that, although all participants believed that teaching NOS is important in the scientific process, most of the participants' lesson plans showed rare evidence of explicit planning to teach NOS. Only three participants had planned to teach NOS explicitly. In other words, the participants actually addressed NOS in their teaching much less than they had claimed. Although the MAT program consistently emphasized that NOS needed to be explicitly addressed, the few cases where participants reported teaching NOS involved instances where students were simply by doing science.

Abd-El-Khalick et al. (1998) discuss how many participants indicate that their views of NOS were mostly changed as a result of their experiences in the program. Even though questionnaire and interview responses revealed that all participants had adequate understandings of several important aspects of NOS, most gave little attention to planning, teaching, and evaluating their students' understandings of NOS. Abd-El-Khalick et al. (1998) suggested that it should be emphasized that explicit attention to NOS is essential. Even though the pre-service teachers had learned about NOS, they were not directly translating those views into their lesson plans on teaching.

In the article entitled "Developing and Acting upon One's Conception of the Nature of Science: A Follow-up Study," Bell et al. (2000) aim to illustrate the factors mediating the translation of pre-service teachers' views of the nature of science (NOS) into instructional planning and classroom practice. The study assesses the influence of temporally separating teaching pre-service teachers about NOS and teaching them explicitly and reflectively.

Thirteen pre-service secondary science teachers participated in the study. As stated in Abd-El-Khalick et al. (1998) study, participants were enrolled in a fifth-year, Master of Arts in Teaching (MAT) teacher preparation program in a rural, mid-sized state university. Their ages ranged from 23 to 33 years with an average of 27 years. Two of the participants did not complete the program, so they were excluded from the study. All of the 11 remaining participants had earned BS degrees (seven in biology, two in physics, one in geology, and one in general science), and three had earned MS degrees (two in biology and one in geology) prior to joining the program. This study utilized the same approaches to Abd-El-Khalick et al., (1998) study with the addition of separating teaching about NOS concepts for teaching them pedagogy.

Seven items open-ended questionnaire and follow-up interviews were used as primary data sources. Data was used to assess pre-service teachers' views of the tentative, empirical, creative, and subjective nature of science; the role of social and cultural contexts in science; observation versus inference; and the functions and relationships of theories and laws. Follow-up interviews were conducted to validate participants' responses to the questionnaire. Other data sources included copies of participants' daily lesson plans for the winter 12-week internship, classroom videotapes and supervisors' weekly clinical observation notes, and each participant's portfolio, a requirement for the completion of the MAT program. The interviews were semi-structured and aimed at validating responses to NOS questionnaire and generate in-depth profiles of the participants' views.

Prior to analyzing the entire data set, in order to establish inter-rater agreement on the identification of the explicit nature of science planning and instruction, three identical, randomly selected samples of each of the data sources were independently analyzed. Instructional objectives, demonstrations, activities, discussions, and/or assessment items that overtly addressed one or more aspects of NOS were taken to be explicit instances. In this analysis, each participant was treated as a separate case. Data from each interview were used to generate a summary of the participants' views on and conceptions of the aforementioned issues. This process was repeated for all the interviews. Next, the researchers reviewed and discussed these summaries in order to reach a consensus on the cohort's beliefs about NOS, the importance of teaching NOS, and the way they would teach NOS until better than 90% agreement among the three researchers was achieved on these analyses. The questionnaires were not analyzed until the end of the data collection process in order to reduce the possibility of biasing Thus, the researchers were unaware of the participants' views of NOS prior to completing the analysis of other data sources.

According to analysis of responses to the open-ended questionnaire and interviews, the authors indicated that participants' views of NOS were, in general, consistent with the contemporary conceptions of the scientific enterprise emphasized in the MAT program. They viewed scientific knowledge, in general, as tentative, although like the previous cohort, participants in this study believed laws to be less tentative than theories. Almost all participants acknowledged the role of creativity in the construction of scientific ideas. Subjectivity, including the individuality of scientists, was viewed as playing a major role in the development of scientific ideas. Finally, like pre-service teachers in the previous cohort, the participants in the present study were able to distinguish between observation and inference and articulate the role of models as representations. In contrast to the previous cohort, all of the pre-service teachers in this study were able to articulate the distinction between theories and laws.

According to analysis of the participants' lesson plans, portfolios, and supervisors' field notes, only 3 of the 14 participants' lesson plans (21%) contained explicit references to NOS. This represented a substantial improvement over the previous cohort. It clearly appeared that the majority of the pre-service teachers had internalized the importance of teaching NOS explicitly. Participants emphasized that teaching NOS required substantial time and that this prevented them from keeping up with other teachers. They also described a lack of confidence in their own understandings of NOS.

Overall, the participants in this study demonstrated a more thorough understanding of how to teach NOS than those of the previous study, both in terms of richer discourse and in terms of pedagogical preference for an explicit activity-based approach. Fewer confused teaching NOS with teaching science process, and still fewer held the view that NOS should be taught implicitly. Bell et al. (2000) discussed that the explicit NOS instruction program affected desirable changes in the participants' NOS views, and separating teaching the pre-service teachers about NOS from teaching them how to teach NOS was more effective than teaching both together.

In the article entitled "Developing Views of Nature of Science in an Authentic Context: An Explicit Approach to Bridging the Gap between Nature of Science and Scientific Inquiry," Schwartz et al. (2004) examined NOS learning developments and attributions during a science research internship course for pre-service secondary science teachers.

Thirteen secondary pre-service science teachers participated in the study. All participants enrolled in a fifth-year master of arts in teaching preparation program in a mid-sized university in the U.S. The participants enrolled in the science research internship program included three main components of the research internship course: (1) the research setting, (2) journals, and (3) seminars. All participants spent an average of 5 hours per week in the research setting for the 10 weeks of the term. Also, the participants wrote journals, which consisted of a research section and a reflection section. The research section includes notes, plans, raw data, and interpretations. In the reflection section, participants responded to sets of focus questions. Lastly, seminars provided opportunity for interns to discuss research settings and experiences, reflect on their experiences in relation to their views of NOS, and develop connections between their research experiences and science teaching. In this section, the authors illustrated interviews to support how the seminars intended to facilitate reflection on the participants' teaching experiences and NOS.

Primary data sources include questionnaires, interviews, journal entries, and participant observations. The authors used the Views of Nature of Science Questionnaire (VNOS-C) and follow up interviews. Schwartz et al. (2004) explained VNOS-C questionnaire which consists of 10 open-ended questions designed to measure views of specific NOS aspects like tentativeness, empirical basis, subjectivity, creativity, socio-cultural embeddedness, observation and inferences, and laws and theories. The data was analyzed by focusing on every single intern's pre-internship VNOS-C responses and corresponding interview transcripts to present their initial conceptions of NOS. Each NOS aspects was scored a "+" to indicate the intern's agreement that the particular aspect is representative of NOS, a "++" to indicate the intern's abilities to articulate the meaning of the aspect in his/her own words, or a "+++" to indicate the intern's abilities to articulate the meaning of the aspect in his/her own words and provide examples in addition to those discussed in prior class sessions. During the whole period of the semester, the authors purposefully focused on changes the interns' views of NOS. The data were compared and contrasted several times for category generation and refinement. All transcripts from the interviews and questionnaires were reviewed and analyzed by the third analysis (triangulation) to consider more valid representations.

According to analysis of pre-internship interviews and interns' VNOS-C responses, only four participants initially held misconceptions about theories and laws. One of these interns held naïve views about tentativeness and creativity as well. The authors described changes by considering "major" which identified a significant switch from naïve views to informed conceptions or "enhancement" which identified where interns held (+) or greater initial views. The result also showed that eleven of the thirteen participants demonstrated major or enhanced views of NOS during the period of the course. Four of these eleven interns demonstrated major improvements in one or more aspects, including their understanding of the relationship between scientific theories and laws. One of the interns demonstrated the most dramatic change with major shifts in his views of the tentativeness, creativity, and the distinction between theories and laws. Also, eleven participants demonstrated a positive change their views of one or more NOS aspects. However, only two participants did not demonstrate changes in their views of NOS because they both presented realist views of science. Last, the results indicated that some factors for change affected eleven interns' views of NOS. Journals, seminars, the research setting approval to influenced changing participants' conceptions of NOS.

Schwartz et al. (2004) discussed that the science research internship program (explicit/ reflective approach) affected desirable changes in the participants' NOS views. The results showed that interns who made the greatest advances began the course with fairly shallow views of NOS. The authors also suggested that the instructors must enhance their pedagogical content knowledge for NOS. The development of NOS views in an inquiry context can be achieved through explicit attention to NOS issues and guided reflection. A limitation of the study was the lack of comparison groups who did not have the research experience or other components of the course.

In the article entitled "The Influence of History of Science Courses on Students' Views of Nature of Science," Abd-El-Khalick and Lederman (2000b) aim to determine what weight history of science courses may have on the learning of NOS goals. The authors begin the introduction by building a case for the importance of teaching NOS. The introduction talks about two pedagogical methods that may influence the teaching of NOS. First, the paper discusses how the use of the history of science (HOS) to teach NOS concepts has long been promoted as a solution to the resistance of NOS objectives. However, the authors' claim as of this paper there are no empirical studies that support the use of HOS as a way to enhance the retention of NOS goals. Second, a teaching approach can either be implicit or explicit and this means how much help/support the teacher gives the students in understanding a concept. The explicit approaches clearly project the desired goals to the students, where implicit approaches embed the concept in the material. The purpose of the research was to determine if history of science courses have an influence on undergraduate students and pre-service teachers' conceptions of NOS. The problem statement generated three research questions. First, how do HOS courses influence college student's NOS conceptions? Second, do students who enter HOS courses with current understanding of NOS concepts gain an enhanced perception of NOS? Third, what HOS aspects, such as course objectives, teaching methods, teacher commitment to NOS and classroom dynamics, impact students learning of NOS concepts?

The authors classified their study as interpretive with data collection continuing throughout the semester, which the research was conducted. The participants were 181 undergraduate and graduate students. 95 were male and 86 female. 1% of the participants were sophomores, 13% juniors, 67% seniors and 19% were graduate students. Most of the students majored in a biological science or general science. 9% of the students were pre-service students. For the study the participants were sorted into two groups. The first group was 166 students enrolled in a HOS course in a fall term at a west coast mid-sized state university. The second group was the 15 pre-service teachers enrolled in a master of arts in teaching (MAT) program at the same university. Of this group 10 of the MAT students were enrolled in a HOS course and were deemed a focus group. All 15 MAT students were enrolled in a science methods course.

Students enrolled in the HOS courses chose to take it as an undergraduate course or graduate course. Requirements were at a greater depth for the graduate students. Three history of science classes were part of the study, they were all 3 credits and were 10 weeks long. There was a survey of the HOS course, studies in scientific controversy course and an evolution course. Only the professor of the evolution course made an explicit commitment to help students learn NOS objectives.

Data was collected from several sources. In order to gauge the students' understanding of NOS, pre-instruction and post-instruction open-ended questionnaires were administered in the first and last week of the fall semester. The questionnaire was adapted from previous researchers. The face validity of the questions was vetted by a panel of professors from science education, science history and a scientist. Modifications generated from panel suggestions were applied to the questions. Semi-structured interviews were conducted post-instruction to have the students justify their questionnaire responses. The participants had access to their pre and post-instruction questionnaires. These interviews included a set of follow-up questions that emerged from conducting the pre-instruction interviews. These sources were used to create a profile of the students' NOS views. The potential interviewees were chosen by random sample for each course so the sample size would be proportional to class size. Within the class, the sample was divided into two subsets. The first subset was interviewed in the first two weeks of class, the second in the last two weeks. Half of the pre-service teachers were interviewed at the beginning of the semester and the other half in the last week. Seventy-eight students were interviewed and the interview lasted from 30 minutes to an hour. All interviews were taped and transcribed. In addition to interviews the courses were attended by primary research and audio-taped, field notes were also generated. The objective of the class observations was to document when NOS aspects were emphasized. These segments were transcribed.

There was sufficient detail in this section about the development of the instruments, which included validity tests. Criteria of what constituted "emphasis of a NOS aspect" was not given by the authors. This makes it difficult to discern what evidence the researchers needed to determine if a segment displayed a positive NOS response.

The data was analyzed into four phases. The first is the generation of the course profiles, data included in the profiles was discussed in the procedures section. The second phase was the validation of the questionnaire. This was accomplished by multiple rounds of analysis in which patterns were sought and summaries from these patterns were produced. Participant profiles were generated from the summaries. Profiles were also generated from the first sub-sample of participants. The questionnaire profiles and interview profiles were compared and displayed good agreement. The third phase of data analysis was the analysis of the questionnaires. Questionnaires of participants that responded to both pre and post questionnaires were analyzed. Each questionnaire generated its own summary and this summary was coded for aspects of NOS. The class standing, course enrolled in and level of NOS understanding determined groups used for producing profiles. The last phase was answering the research questions. The first question was answered for each HOS course. The second question considered what course aspects influenced the learning of NOS aspects. The third question looked at how prior adequate NOS knowledge influenced the post HOS course NOS views of the participants. Positive influence means a prior NOS aspect was enriched. A view was considered enriched if the concept was stated more clearly and used a historical example to support the view.

In general, the method section was well organized and detailed, and therefore, the care with which the research was conducted was apparent. However, the methods section did not state what theoretical framework was used to inform the study. Along with the lack of a framework, any theoretical assumptions influencing the researchers were also not stated. Without explicit assumptions there is no evidence for the researchers' theoretical standpoint. Finally, no mention was made on what bias the researchers may have brought into the study, either through their own epistemological stance or the instruments and methods used. Therefore, if the authors had a strategy to minimize bias; what it was and how it may have been employed was not discussed.

This paper presented the results in table format and in text form. The first table displayed the percentage of naïve vs. informed views for ten NOS aspects in the pre-instruction questionnaires. The students in HOS courses were compared to the pre-service teacher group. Each of the ten points was expanded in the text. The next table displayed the changes in participants' views by course. The changes in NOS views were slight. Only 3% of participants had changes in 2 or more NOS aspects. Even though overall results amongst all participants in all HOS courses were small, two interesting things emerged. First, students who entered HOS courses with adequate NOS views had relatively more participants demonstrate a positive change in NOS views. Second, most of NOS view changes were in instances where NOS concept was explicitly taught. The evolution course taught NOS views explicitly and the percentage of change in one aspect amongst the students was 27% for the student group and 40% for the pre-service teacher group. In the Survey course change in one aspect amongst the students was 17%, and in the controversy course change in one aspect was 17%.

The results were presented with detail and from multiple perspectives. The authors did state that change was slight. The concept of slight is vague and the table organized by courses seems to contradict this appraisal. While it is true, that change was generally only demonstrated in one aspect, the results did not state if all NOS aspects carried the same importance. The authors state that the most significant important finding in the study was that HOS courses only had a small influence on NOS views. They state that is study does not give empirical support for the claim that HOS courses improve NOS views. The paper gives four factors that may impede using HOS. First, the paper claims there appear to be an inherent barrier in HOS as a tool for learning NOS aspects.

The authors believe this is not unexpected in light of conceptual change theory. The current conceptual framework of students maybe too incongruent with the framework needed to find meaning in historic materials. The second barrier stated by the paper is the choice of professors to use implicit approaches to teaching NOS aspects vs. explicit ones. As noted before, virtually all changes involved NOS aspects that were taught explicitly. The third barrier is the misconceptions of NOS held by students coming into the HOS courses. The fourth barrier may be that the HOS course objectives may not give priority to NOS aspects. The discussion concludes with a suggestion that students should be given an adequate framework of NOS concepts before entering HOS courses. This may help students leave the HOS course with enhanced NOS views.

While the results of the study do suggest there are problems with using HOS to teach NOS, the four stated in this paper are pedagogical issues. The last three factors can be remedied by changes in teaching approaches. The first factor, an inherent problem with using HOS due to conceptual change problems was not well supported. If misconceptions can be handled applying conceptual change theory, it is reasonable to think that it can be applied to issues of teaching with HOS. The results section is the first place any learning theory is employed in support of the author's claims. It would be useful to have had the conceptual change theory introduced in an earlier section of the paper.

The paper discusses four implications that emerged from the study. First, HOS courses should use explicit approaches to teaching NOS aspects. Second, explicit approaches may not be enough in the face of misconceptions. Exposure of the misconceptions coupled with the use of explicitly delivered HOS examples may be more useful than explicit approaches alone. Third, HOS alone will not help learners gain adequate NOS views. Students should have adequate NOS views before entering HOS courses. Fourth, HOS is an established and separate discipline, and it should not be assumed HOS goals align with pre-service teachers. There should be discourse between science educators and historians to help them be more aware of science teachers needs.

The paper concludes with recommendations for further research. The authors state this is the first paper to study the influence of HOS on college students and pre-service teachers NOS views, and therefore further research is needed to validate the findings in this study, this validation is critically important in view of the limited benefit HOS courses had on NOS views, in light of the continued belief that HOS is useful in teaching NOS. The second research area should be in how many HOS courses would be the most useful in enriching or changing NOS views. Third, the gains made by students with prior NOS knowledge should be studied further. Fourth, if collaborative efforts between historians of science and science educators should occur, research should focus on explicitly taught NOS in context of science courses, science education courses and history of science courses. Finally, more research is needed to determine if a form of NOS PCK is necessary to effectively teach NOS and history materials may form the basis for this PCK.

In the article entitled “Influence of a Reflective Explicit Activity-Based Approach on Elementary Teachers’ conceptions of Nature of Science,” Akerson, Abd-El-Khalick, and Lederman (2000) aim to assess the influence of set of activities, and implemented within an explicit, reflective approach, on pre-service elementary teachers’ conceptions of NOS. Two research questions guided this study: (1) what meanings do pre-service elementary teachers ascribe to some aspects of NOS?, and (2) what is the influence, if any, of using a reflective, explicit, activity-based approach with pre-service elementary teachers' views of the aspects of NOS which were indicated in theoretical paper of this study? The introduction section begins to describe problem statement. The authors clearly identify the main goal of science education community, the problem, and the gap in the literature, which this study will address. Then, they mention about previous research on improving science teachers' views of NOS and definition and consensus seven aspects of NOS. The aspects which are examined in this study are that scientific knowledge is tentative, empirically based, subjective, partly the product of human inference, imagination, and creativity, and socially and culturally embedded. The authors also add two important aspects are the distinction between observations and inferences, and the functions of and relationships between scientific theories and laws.

Fifty students were participated in this study. Participants were enrolled in two sections of an elementary science method course. Twenty-five undergraduate students (23 female and 2 male) were enrolled in the first section, and 25 graduate students (22 female and 3 male) were enrolled in the second section. The majority of the undergraduate participants (90%) had completed 10–16 science credit hours. Most of the graduate students (85%) had completed 12–15 science credit hours. After the authors mentioned about the context of elementary science method course, the data collection procedure was clearly explained. An open-ended questionnaire in conjunction with semi-structured interviews was used to assess participants' views of the target aspects of NOS. All participants were administered the questionnaire before and at the conclusion of the course. In addition, a total of 40 participants (20 from each course) were selected for interviewing. In each course section, 10 students were randomly chosen for pre-instruction interviews, and the other 10 students were interviewed at the conclusion of the study. The interviews aimed to generate in-depth profiles of participants NOS' views. Also, student reflection papers and a detailed researcher log served were used as additional sources of data.

During the first six hours in the course, the participants were engaged in 10 different activities that explicitly addressed the seven target aspects of NOS. Two of the activities addressed the function of and relationship between scientific theories and laws. Two other activities addressed difference between observation and inference, and the empirical, creative, imaginative, and tentative nature of scientific knowledge. Four other activities targeted the theory-laden and the social and cultural embeddedness of science. Finally, two activities were used to reinforce participants' understandings of the above NOS aspects. Each activity was followed by a whole-class discussion that aimed explicitly to highlight the target aspects of NOS. Participants were often asked to think about how that content and activities were related to NOS. The authors provided participants to reflect their ideas, both orally and in writing. Also, the authors explicitly talk about classroom discussions and written reflection in this paper. According to the authors, these discussions and written reflections might help to illustrate the importance of explicit prompts to get students to think about and reflect on different issues related to NOS.

The questionnaires and follow-up interview transcripts were separately analyzed and compared by the second and third author for the purpose of establishing the validity of the open-ended NOS questionnaire. The questionnaires were thoroughly read and searched for initial patterns. The same process was repeated with the corresponding interview transcripts. This analysis indicated that the profiles of participants' NOS views. Next, all NOS questionnaires were analyzed to generate pre- and post-instruction profiles of participants' views of NOS in the two course sections. In this analysis, each participant was treated as a separate case. Data from each questionnaire were used to generate a summary of each participant's views. This process was repeated for all the questionnaires. After this initial round of analysis, the generated summaries were searched for patterns or categories. Several rounds of category generation, confirmation, and modification were conducted to reduce and organize the data satisfactorily. Moreover, analyses of participants' reaction papers were used to corroborate or otherwise modify the views derived from analyzing NOS questionnaires. Finally, pre- and post-profiles were compared to assess changes in participants' views. These changes were compared across the two course sections.

According to analysis of the data, the authors illustrate results section by considering students' pre-instruction and post-instruction NOS views. First, the result indicates that undergraduate and graduate participants' pre-instruction views of the distinction between observation and inference and the relationship between theories and laws, as well as their views of the subjective, and social and cultural NOS were very similar. More than half of all participants, both graduate (52%) and undergraduate (60%), were not able to adequately articulate the distinction between observation and inference. These participants failed to realize the role of inference in deriving scientific constructs. In other words, these participants seemed to believe that scientists are able to find about phenomena only if these are directly accessible to the senses. Almost all participants explicated inadequate views of the function of the relationship between scientific theories and laws. Participants failed to recognize the well-substantiated nature of scientific theories. They did not seem to realize that theories and laws are different kinds of scientific knowledge and serve different functions, and that one does not become the other. They believed in a hierarchical relationship between theories and laws whereby theories become laws when they are proven. Also, nearly one half of the participant failed to recognize that scientists' training and disciplinary backgrounds, their theoretical commitments, philosophical assumptions, prejudices and preferences, as well as the social and cultural contexts in which they live do influence their work.

However, more graduate participants held adequate views of the empirical and tentative NOS, whereas more undergraduates held adequate conceptions of the creative and imaginative NOS. Only one undergraduate participant (4%) and seven graduate participants (28%) expressed adequate views of the empirical NOS. These participants noted that science is different from other disciplines because scientific claims should be consistent with empirical observations. The greater majority of participants, however, did not include observations of natural phenomena as a characteristic factor that sets science apart from other disciplines, such as art. Similarly, the greater majority of participants (92% of undergraduates and 84% of graduates) did not hold adequate views of the tentative NOS. As noted above, many participants believed that scientific laws are proven or absolute and not subject to change. Most participants (76% of undergraduates and 84% of graduates) did not demonstrate adequate understandings of the role of human inference, imagination, and creativity in generating scientific claims. The lack of substantial differences between undergraduate and graduate participants' NOS views is consistent with research findings that indicate that these learners' NOS views are not significantly related to their science content knowledge. None of the participants held adequate views of all seven investigated NOS aspects at the beginning of the study.

On the other hand, more participants held adequate views of the target aspects of NOS at the conclusion of the study. With the exception of views related to the creative and imaginative NOS, where undergraduates showed relatively more gains, changes in undergraduate and graduate participants' views were comparable. Many undergraduate (80%) as graduate participants (40%) exited the course with better understandings of the role of creativity and imagination in science. These participants believed that science, like art, required creativity and imagination. About 40% of all participants no longer believed that creativity was only used in the initial stages of scientific inquiry, but that it was an integral part to all stages of scientific investigation.

However, the observed changes were not consistent across the investigated NOS aspects. Changes in participants' views were particularly pronounced with regard to the tentative NOS, the distinction between observation and inference, and the functions of and relationship between scientific theories and laws. Changes were also evident in participants' views of the empirical, subjective (theory-laden), and social and cultural NOS. Some undergraduates (32%) and graduate (52%) expressed more adequate views of the empirical NOS at the conclusion of the course. These participants indicated that observations of the natural world set science apart from other disciplines such as the arts. Substantial changes were evident in participants' views of the tentative NOS. Compared with 8% and 16% of undergraduate and graduate participants, respectively, at the beginning of the study, 52% and 56% of these participants elucidated more adequate views of the tentativeness of scientific knowledge at the conclusion of the course. Compared with 40% of undergraduates and 48% of graduates who expressed adequate views of the distinction between observation and inference at the beginning of the study, 80% and 84% of undergraduate and graduate participants, respectively, elucidated adequate views of this aspect of NOS at the conclusion of the study. These participants seemed to appreciate the inferential nature of atomic structure. At the conclusion of the course, about half of all participants (48% of undergraduates and 56% of graduates) adopted the more adequate view that scientific theories and laws were different kinds of scientific knowledge. These participants noted that whereas scientific theories are inferred explanations for observable phenomena, scientific laws state, identify, or describe relationships. Lastly, little change was observed in participants' views of the subjective (theory-laden), and social and cultural NOS. On exiting the course, more than half of participants (52%) demonstrated adequate views of the theory-laden NOS (an increase of 20% and 8% for undergraduate and graduate participants, respectively). Similarly, about 75% of participants (an increase of 24% and 16% for undergraduate and graduate participants, respectively) demonstrated more adequate views of the social and cultural NOS. In general, these participants recognized that scientists' prior knowledge, personal backgrounds and viewpoints, as well as other human elements, influence the ways in which scientists interpret empirical evidence.

The authors conclude that the explicit reflective activity-based approach to NOS instruction undertaken within the context of the investigated science methods course was effective in enhancing participant pre-service elementary teachers' views. Participants made substantial gains in their understandings of the target aspects of NOS. However, as noted earlier, these gains were not consistent across those NOS aspects. Participants made relatively more gains in their understandings of the tentative, and creative and imaginative NOS, as well as the distinction between observation and inference, and the functions of and relationship between theories and laws. Less substantial gains were evident in the case of the subjective (theory-laden), and social and cultural NOS.

All in all, in examining the studies done by Abd-El-Khalick et al. (1998), Abd-El-Khalick et al., (2000), Akerson et al., (2000), Bell et al., (2000), and Schwartz et al., (2004), it appears that explicit/reflective NOS instruction is a most effective way to teach NOS and to conceptually change and improve students' views of NOS. However, all these studies except Bell's et al. research show that although explicit/reflective NOS instruction is an effective way, many participants' views of some aspects of NOS were not still improved. Participants mostly failed to explain the difference between scientific theories and laws, and a role of social and cultural factors in the scientific knowledge. As a result of these five studies, explicit/reflective teaching of NOS expects learning outcome, purposeful teaching that draws students' attention to relevant NOS ideas, and assessments that measure students' learning about NOS.

Pedagogical Content Knowledge for NOS and NOSI

The pedagogical content knowledge (PCK) for nature of science and scientific inquiry (NOS/NOSI) refers to the teachers‘ understandings of NOS/SI and the relationship between such understanding and how to teach it. Comparable to other traditional science contents, NOS/SI could be viewed as part of the subject matter knowledge (SMK) that teachers need to teach and therefore need to develop their PCK for teaching. In other words, NOS/SI may be viewed as a particular *topic* within the domain of science. This is further evidenced by the inclusion of NOS as one of the content standards in the *National Science Education Standards* (NRC, 1996; NGSS, 2014). Thus, while teachers' own views of NOS/SI can be considered part of their SMK, NOS/SI can also be viewed as analogous to other content a teacher might teach, and for which they would develop PCK. According to Abd-El- Khalick and Lederman (2000), the PCK for teaching NOS refers to the "knowledge of alternative ways of representing aspects of NOS [that] would enable the teacher to adapt those aspects to the diverse interests and abilities of learners" (p. 692). Moreover, they recommended that for a teacher who has developed PCK for teaching NOS, they should be able to comfortably discourse about NOS, design science based activities that would help students comprehend those aspects, and contextualize their teaching about NOS with some examples or stories from history of science (p. 693). The results from several research studies in PCK revealed that PCK could be developed through teaching experience. Lederman (2007) recommended that for science teacher educators to understand how teachers develop their PCK for teaching NOS, the studies that adopt the PCK perspective as a lens for research on the teaching of NOS (p. 870) are needed.

As explained above, PCK for NOS and NOSI is complicated and interrelates multiple fields of knowledge (Schwartz & Lederman, 2002) and surfaces through multiple instructional dimensions (Bartholomew, Osborne, & Ratcliffe, 2002). Research has shown that preservice elementary teachers can improve their understandings of NOS and NOSI through appropriate instruction (Abd-El-Khalick & Lederman, 2000; Abd- El-Khalick et al., 1998; Akerson et al., 2000; Bell et al., 2000; Eichenger, Abell & Dagher, 1997; Khishfe & Abd-El-Khalick, 2002; McComas et al., 1998; Rudolph, 2000; Schwartz et al., 2004), and in some cases transfer their understandings to classroom instruction with support (Brickhouse, 1990; Hanuscin et al., 2011; Nilsson, 2008). However, the kinds of support required aiding new teachers in teaching NOS and NOSI may not be possible to achieve for each teacher. Therefore, there is a gap to explore various strategies for helping teachers (both pre-service and in-service) to not only learn about NOS and NOSI for themselves, but to learn how to teach them to students (Lederman, 2007).

Empirical Studies of Science Teachers' PCK for NOS and NOSI

The early attempts to study the PCK for teaching NOS/SI were Abd-El-Khalick and Lederman (2000b) and Schwartz and Lederman (2002). Abd-El-Khalick and Lederman (2000b) propose that teachers' PCK for NOS should include knowledge of a wide range of related examples, activities, illustrations, demonstrations, and historical episodes. Schwartz and Lederman (2002) proposed an emerging model of critical elements for the development of PCK for NOS and application of that knowledge in the classroom. According to these researchers, knowledge of NOS, knowledge of science subject matter, and knowledge of pedagogy are just three of the elements that blend to form PCK for NOS. They argue that to be able to teach NOS, teachers must intend and believe they can teach NOS, must believe that their students can learn NOS and must have the knowledge base for teaching NOS.

Schwartz and Lederman (2002) examined the knowledge, intentions, and instructional practices of two beginning secondary science teachers, and attempted to teach NOS during their student teaching experience and during their first year of full-time teaching. For their research, a case study comparison of two teachers, both of whom the authors previously encountered as part of a separate study (Lederman, et al., 2001), was conducted. The intent was to elucidate the progression and challenges of each from their learning about NOS as subject matter, to their attempts to translate this knowledge in classroom practice. The comparison, it was assumed, would provide greater insight into the complexity of this transition, and add to the existing literature regarding implementation of NOS-related instruction.

As stated, the two subjects chosen for the case study were members of a previous study, were enrolled in a master's of arts teaching program, and were selected by the author or as "an interesting contrast." They had differing degrees of NOS understanding, in addition to different backgrounds in, and experiences with, science. It is stated that the researchers have data on these two subjects from their first days in a master's program, and thus can be reasonably assumed that their knowledge of the subjects is adequate to inform their selection. The subjects, Rich and Laura, are similar in age, education (Rich has an M.S.in his field, Laura a B.S.), and teaching experience (Rich has taught undergrads as a graduate student, but is new to secondary level, and Laura has no secondary teaching experience).

The study, in general, comprised six different components. First, the subjects were taught about various aspects of NOS, and attempted for the first time to teach NOS. Subjects then took part in an extensive research internship that included NOS instruction and guided journal reflections. Thirdly, explicit instruction and NOS resources were provided to help facilitate the teaching of NOS. Subjects then completed a full-time student teaching experience, followed by an exit interview in which they discussed their growth and overall changes in regards to NOS. Lastly, the subjects were contacted and surveyed at the halfway point of the first year of their first fulltime teaching assignment.

In terms of the data collected and its subsequent analysis, the authors separate this into two components, one directed towards the subjects' developing understandings of NOS, the second concerned with characterizing their attempts at teaching NOS. The authors utilized the VNOS-C (Lederman et al., 2002) at the onset of the investigation to assess subjects' knowledge of NOS, and it was administered two more times, once at the completion of the first class, and once at the end of their teaching internship. The scoring of these is detailed by Schwartz and Lederman, and includes a scale on which articulation; the providing of examples, and evidence of the interconnectedness of NOS to traditional science content was highly valued. The scoring results of the two researchers were corroborated during the second and third of the interviews through the use of member checks. These were conducted at the end of the first class, and at the midway point of the student teaching semester to ensure accuracy in interpretation, and to help illuminate any changes that may have occurred.

An analysis of classroom observation and subject-participation, in addition to journal entries and transcriptions of conferences and meetings provided further evidence of changes in NOS beliefs. This also served to provide a gauge for judging subject's interest and motivation to learn about and incorporate NOS in classroom practice.

To facilitate the analysis of the planning and teaching of NOS, a plethora of data sources were utilized. In the first class, mini-lessons were planned for and taught, in addition to traditional lesson plans and NOS activity cards. In the second phase, subjects responded to a simple question, "What is important to teach in science?" This question was administered by a party not affiliated with the study, thus, in the view of the authors, the results are more representative of subjects' true views, and not biased by the perception of what might be the answer expected from the researchers.

During student teaching, formal observations were conducted, followed by conferences in which the subjects discussed their opinions regarding what fostered or hindered the teaching of NOS, in addition to reflecting on the overall effectiveness of their teaching efforts. An interview was also conducted at the end of the student teaching session. Similar to the post-observation meeting, the subjects were asked to reflect on their effectiveness in implementing NOS instruction, and how various factors of the preparation program may have contributed to their successes or failures. These interviews were audiotaped and transcribed. Lastly, six months into their first teaching assignment, both subjects were contacted for one final interview, similar to the previous ones, except that all data took the form of self-reporting, as no subsequent observations were conducted once the student teaching experience concluded.

The authors utilized the numerous data sources to triangulate the data, develop rich profiles of the two subjects, and relate attempts at NOS instruction with subjects' views of NOS. This was done by the first researcher and then confirmed or contradicted by the second, with all discrepancies discussed until consensus was reached.

The results are presented in three distinct sections. The first of which details initial NOS views, changes during the first phases of the study, and teachers' initial attempts to teach NOS. The second section examines subsequent attempts to teach NOS and related changes to NOS understandings. Lastly, instructional practices during subjects' first full-time teaching assignment are discussed. The scores of each subject's VNOS administrations are presented, in addition to a summary of attempts at teaching

NOS during student teaching. Each case study is presented separately in extensive detail. In conclusion, and in summary of their findings, the authors compare and contrast Rich and Laura.

In summary, both Rich and Laura appear to progress to a point where they see NOS as existing in all scientific content, “the nature of the beast,” as they put it. Their attempts at integrating NOS into science content were successful as were, to some degree, their attempts explicitly teaching NOS. This was due, Lederman and Schwartz contend, to both the success they experienced in the program leading up to their first full-time job, and to the fact that they “held strong intentions and beliefs that NOS was an important topic to include in their teaching” (p. 231). This determination allowed them oftentimes to side step the traditional pitfalls that sidetrack other novice teachers (e.g. classroom management, organizational issues). Rich, in addition, over the course of the study developed a more integrated view of the various aspects of NOS, no longer seeing them as separate entities, but as integrated and overlapping components.

Limited subject-matter knowledge and a less mature conception of NOS did serve to limit Laura’s attempts at incorporating NOS, though the latter was mitigated by the availability of NOS activity guides and instructional materials, which she utilized systematically, oftentimes with limited insight into the prevalent aspects of NOS included therein. In addition, the authors conclude that additional professional development is needed to help foster more mature and sophisticated pedagogical content knowledge (PCK) with respect to NOS.

Rich, while describing an inquiry-rich classroom, as the ideal place to foster mature views of NOS in his students, did not reflected this in his classroom practice. It seemed that his limited experienced and underdeveloped PCK made this a difficult task to complete with consistency.

Both subjects did, it should be noted, fall prey to the usual pitfall evidenced by many in their first full-time teaching assignment, though Rich did make more creative and effective attempts at NOS instruction. Classroom management and organizational issues, in addition to the difficulties in navigating an unfamiliar curriculum, and, in Laura's case, unfamiliar subject matter did, at times, relegate NOS to more of an "instructional after-thought." Explicit NOS instruction was rarely planned for, and in Laura's case, was almost exclusively didactic in nature, much like her early attempts during student teaching.

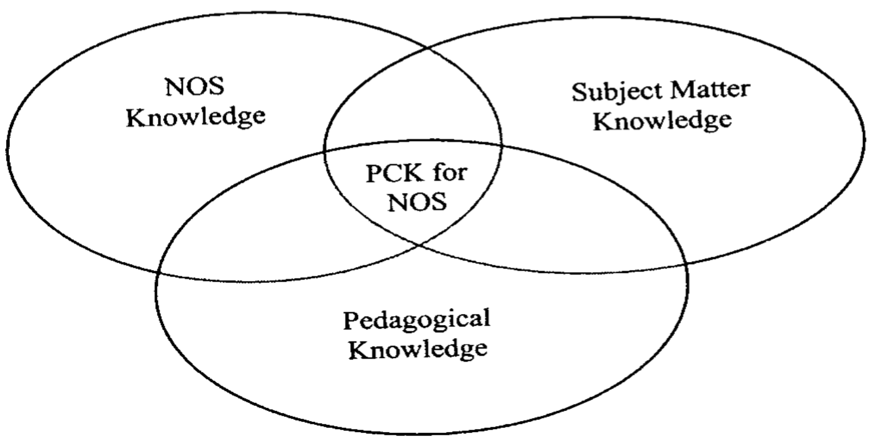

Figure 6. Pedagogical Content Knowledge for Nature of Science

The researchers concluded that these results suggest that teachers need to develop PCK for NOS, just as they must for their subject matter, if their efforts are going to be optimized. They suggest a model, represented in Figure 6, which the professional development needs to focus on nurturing the complex relationship between content knowledge, traditional pedagogy, NOS, and the interactions among the three (see Fig. 6).

In addition, teachers must be motivated, or have the intent, to teach NOS, and see its worth as an educational objective. Teachers without adequately developed PCK for NOS will continue to either fall victim to traditional restraints (e.g. curriculum) when they lack intent, or may simply limit their effectiveness in creating informed views of NOS in their students.

In light of the Lederman (2007) recommendation, researchers tried to focus on PCK for NOS/SI based on the various models of PCK (Shulman, 1986; Grossman, 1990; Magnusson et al. 1999). The first attempt after Lederman's recommendation is Hanuscin et al. (2011). Hanuscin, Lee, and Akerson (2010) examined the classroom practices of three experienced elementary teachers who, through explicit and reflective instruction, successfully improved their students' views of NOS. They also tried to find out how to teachers' understanding of NOS manifests itself in their classroom practice, including their instruction, but also their assessment of students' ideas.

Although there are alternative methods of PCK, authors used Magnusson et al.'s (1999) model of PCK as a theoretical framework of the study because they assumed that this model could serve as useful tools for researchers. However, they recognized that PCK is more than the sum of the Magnusson et al. (1999) model's parts. Thus, the authors also sought to examine the interplay between the components of PCK as teacher's enacted NOS instruction.

Three experienced teachers participated in the research component of the project over 3 years. The authors considered that these teachers "effective" in teaching NOS because they had a clear rationale and commitment to teaching NOS as well as the ability to emphasize NOS explicitly in their instruction. Throughout interviewing these teachers' students, teachers' instruction had positively impacted their students' views of NOS. The researchers used multiple data sources in order to understand and capture teachers' PCK inaction more deeply. In this sense, the researchers collected data as: (1) questionnaire and interview data collected at the beginning and end of the project to document teachers' own understanding of NOS; (2) field notes and transcripts from 15 full and/or half-day professional development sessions held over a 3-year period; (3) videos, lesson plans, and field notes from 15 separate observations of teachers' classroom teaching of NOS over the course of the project; (4) video stimulated-recall interviews conducted with teachers following each of these classroom observations; (5) videos, transcripts, and artifacts from teachers' presentations of their teaching experiences at both a state and regional professional conference; (6) teachers' written contributions to professional publications, including two chapters in NSTA monographs; (7) individual interviews conducted with teachers at the end of Years 1 and 2 of the project; and (8) a focus-group session held with teachers at the conclusion of the project.

Modified analytic induction was utilized to develop coding schema and identify emerging themes. For the credibility, each of the researchers analyzed independently. Four overarching criteria were used for judgment about what constituted an explicit approach. These are; (a) teachers planned to teach a particular aspect of NOS; (b) students were made aware of the target aspect of NOS; (c) students were provided an opportunity to discuss and/or reflect on their ideas about the target aspect of NOS; and (d) teachers elicited students' ideas about NOS before, during, or at the conclusion of the activity. Themes and categories emerged through an iterative process of engagement and reengagement with the data. They used the matrices for identifying gaps, overlaps, patterns, and trends in order for triangulation and track themes across all multiple data sources for individual teachers. Through this process, authors identified common aspects of teachers' instruction and assessment of NOS. However, it is not clear how the analyzed each data sources through the lens of theoretical framework of this study which was based on Magnusson et al. (1999).

Related to the first questions, the authors identified three distinct, but related, ways through which teachers transformed their understanding of NOS into forms accessible to their students. These consisted of (1) translating the language of the reforms into "kid-friendly" terms, (2) operationally defining NOS in the context of inquiry-based experiences, and (3) drawing analogies to NOS aspects using children's literature. The authors clearly discussed each of these transformations and what they reveal in terms of teachers' PCK for NOS.

For the second research question, the authors represented teachers' PCK for NOS based on Magnusson et al.'s (1999) PCK model. They synthesized the way in which teachers drew on their subject matter knowledge, general pedagogical knowledge, and knowledge of their context as well as the interactions between the various knowledge bases that are integrated in the enactment of their PCK. In the figure below, the authors have foregrounded particular aspects of teachers' PCK that were more developed (e.g., instructional strategies) and used solid arrows to indicate the paths the various knowledge bases on which teachers drew most heavily. Dashed lines indicate a path or influence that was not fully utilized as teachers enacted their PCK for NOS (see Fig.7).

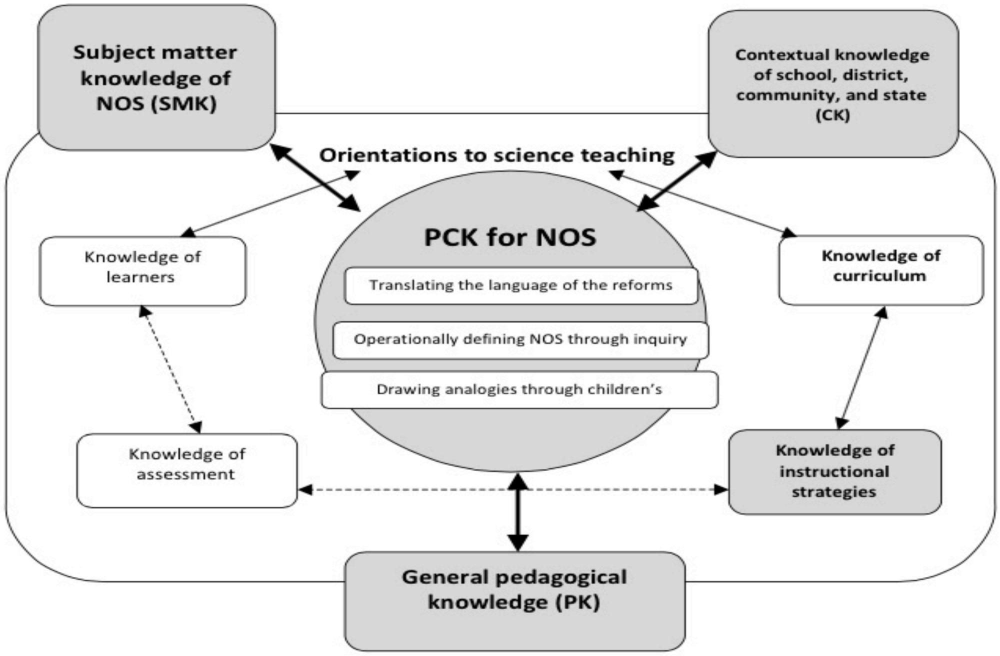

Figure 7. Teachers' PCK for NOS. The Illustrative Model of Hanuscin et al. (2010)

The authors argue that although teachers were able to successfully enact explicit-and- reflective instructional strategies to teach NOS, they did not specifically assess the impact of that instruction on their students' understanding of NOS. Through participation in the professional development program, the authors stated that their teachers had developed knowledge of institutional strategies for teaching NOS, but not the complementary knowledge of assessment. The authors believe that is the reason that well-designed classroom assessment could provide the necessary evidence for teachers to realize whether their instruction is effective in addressing students' ideas about NOS. In other words, classroom assessment is a crucial element of understanding how much students learn about NOS or how the teachers make effective teaching.

As a result, helping teachers teach NOS effectively is a difficult and complex task for teacher educators. By utilizing PCK as a lens to understand teachers' classroom practice, the authors were able to identify important gaps in teachers' knowledge—gaps that could remain undetected by focusing more narrowly on teachers' use of instructional strategies and the impact on student learning. The authors recognized that professional development efforts could be enhanced by expanding the focus to help teachers develop other aspects of their PCK for NOS, rather than focusing solely on helping teachers develop their skills for particular instructional strategies.

The other highlighted finding of this study was a need for "educative curriculum materials" for NOS. Educative curriculum materials can help teachers add important ideas to their repertoires, including subject matter knowledge of NOS and students' likely ideas. In this manner, they believed educative curriculum materials might help address the tension between teachers' desire for prepackaged NOS "activities that work" and professional developers' desire to avoid providing a "bag of tricks." The authors also suggested that teachers should use assessment to guide and modify instruction. They should be able to "demonstrate that they are effective by successfully engaging students in the study of the nature of science" and that "assessments of effectiveness must include at least some demonstrably positive student outcomes."

Overall, there was a clear focus for the study, and the authors clearly described the model, theoretical framework, and philosophy of the study. The authors also described the methodology, which include research method, design, and study context. I think the methodology, procedure, and design were appropriate for the study and clearly aligned with the problem. Only weaknesses of this study is that how to analyze each of the data appropriate, coherent, complete and aligned with the research questions and theoretical framework. There is no clear information about how to analyze each data. The researchers must describe and explain data analysis and why these analyzing is appropriate, coherent, and aligned with the research questions. However, the authors did a great job making argument and interpretations supported by the data and linked to prior literature. This study also supported the applicability of Magnusson et al.'s PCK model to characterize and examine teachers' PCK for NOS, and to illustrate how this model can be used to develop a more holistic view of teachers' classroom practices related to NOS, including teachers' use of assessment.

Faikhamta (2012) examined a broader understanding of the characteristics of a PCK based NOS course, and its impact on the development of in service teachers' learning about NOS as well as their orientations to teaching it. In this study, the author used a qualitative research approach based on an interpretive paradigm because she argued that this method was used in order to build an understanding of how in-service teachers developed their understandings of NOS and orientations to teaching NOS. Twenty-five Master of Education in Science Education in-service teachers participated in this study and enrolled the Nature of Science Course (NOSC). All participants had 1 to 10 year teaching experiences in primary or secondary schools. NOSC involved 15 weeks with 2 hours of instruction. The goal of the course was to enhance science teachers' understandings of NOS and it's teaching. Hanuscin et al. (2011)'s suggested model for teaching NOS was used as a conceptual map to design learning activities in the course. Thus, the course was structured in line with PCK components which are; (a) orientations to teaching NOS, (b) knowledge of science curriculum, (c) knowledge of students' conceptions about NOS, (d) knowledge of teaching strategies, and (e) knowledge of assessment of students' learning about NOS.

The author suggested to divide NOS into three categories; scientific worldview, scientific inquiry, and scientific enterprise. Mainly she considered NOS with some tenets which are (a) science cannot provide answers to all questions, (b) since scientific knowledge, while durable, has a tentative character, and (c) scientific knowledge relies heavily, but not entirely, on observation. In the second aspect, (a) science demands evidence and is a (b) blend of logic and imagination. Also (c) experimental evidence requires rational arguments and skepticism. (d) Scientists are creative, and scientists require accurate record keeping, peer review and replicability. Finally, in the third aspect, (a) science is viewed as a series of complex social activities, (b) science and technology impacts each other, and (c) scientific ideas are affected by their social and historical context. The specific research questions were:

- What is the impact of a PCK-based NOS course on in-service teachers' understanding of NOS, and orientation towards teaching NOS?
- In which ways do in-service science teachers develop their understanding of NOS and orientations to teaching NOS in the context of the PCK-based NOS course?

Data was collected with pre- and post- questionnaires (questionnaire were adopted from different sources which explained below), weekly electronic journals, course assignments, and field notes. For the understanding of the first question that is related to the impact of PCK-based NOS course on participants' understanding of NOS, and orientation towards teaching NOS, an open ended questionnaire was used as the primary data, consisting of seven questions; six items related to the understanding of NOS and one item related to orientations towards teaching NOS. The questionnaire relating to teachers' understanding of NOS specifically focused on the "definition of science", "characteristics of science", "differences between law and theory", "tentativeness of scientific knowledge", "scientific inquiry", and "the interaction between science, technology and society". For the validation of the questionnaire, the author mentioned that reviewing the content with panels of experts at the university and experimenting with other groups of Master's degree students enhanced validity of the questionnaire.

For the second research question, which aimed to examine participants' learning about NOS and orientations to teaching NOS through the course, the participants' journal entries were the primary data source. The guided questions in the journal were as follows: What have you learned from the course?; What do you still not under- stand?; What are you going to study further?; and What are your suggestions about today's teaching and learning activities? Interestingly, the author did not use interview even though it is a suggesting data collection type when eliciting participants' PCK.

For the analysis of the data, the participants' responses to open-ended questionnaire were placed into three categories; "naïve", "partially informed", or "informed". Also, for the second part of the first question, the responses were categorized according to nine different orientations by using the PCK framework suggested by Magnusson et al. (1999); (1) process, (2) academic rigor, (3) didactic strategies, (4) conceptual change, (5) activity-driven, (6) discovery, (7) project-based science, (8) inquiry, and (9) guided inquiry. For the second research question, data from field notes, journal entries, and work sheets were focused on the identification of trends or patterns in the statements made by the participants, and developed categories and their properties on the basis of the data through an iterative process. However, the author did not mention about how to triangulate data for inter-coder reliability. Also, according to recent studies

(Hanuscin, 2013; Hanuscin et al. 2011; Wabeh & Abd-El-Khalick, 2014), lesson plan analysis and observations from participants' practicing are most important data in order to understand participants' PCK even PCK for teaching NOS.

The results indicated that a PCK-based NOS course helped in-service science teachers develop deeper and more informed understandings of NOS and the related teaching orientations. Prior to the instruction, many in-service teachers held naive views of the target aspects of NOS, especially in the aspects of law and theory, and scientific knowledge. The majority of in-service teachers had a more informed understanding of NOS in the post-instruction questionnaire. Compared with in-service teachers' understanding of other emphasized aspects, their views of the law and theory aspect seemed more resistant to change. In addition, the in-service teachers shifted their orientations to teaching NOS from an implicit science process and discovery approach towards an explicit inquiry-based approach. They learned the sequences of explicit inquiry-based teaching strategies, specifically that effective teaching activities should begin by motivating students' interest, eliciting prior conceptions of NOS, asking students' questions related to target NOS aspects, and that students should have a chance to carry out hands-on activities. The author argued that 15 weeks of the course may not be enough to promote participants' understanding of NOS and the retention of their views, and she referred back to Akerson et al. (2006) study. However, she did not look at participants' retention views of NOS after the 15 weeks NOS course.

Also, the development of in-service teachers' understandings and orientations to teaching NOS resulted from explicit discussions. It was showed that the in-service teachers had opportunities to explicitly reflect on their own interpretation of NOS and its teaching. This allowed them to consider the fundamental ideas about certain aspects of NOS, as well as the goals of teaching and learning NOS. However, participants could be observed in their own teaching of NOS, and their lesson plan could be analyzed in order to conclude this study as supported evidence of teaching NOS effectively. However, the author indicated that this is a limitation of this study. This finding also supported the idea that metacognition should be embedded in various contexts like the findings in the study of Akerson et al. (2006). As found in this study, metacognition is embedded in a series of activities including role modeling, analyzing research articles and documents, engaging content- and non-content embedded NOS instruction, reading scientists' biographies and designing assessment tools. The in-service teachers must be encouraged to elaborate their understandings of this aspect through reflection on other activities such as non-explicit, content-embedded instruction.

Overall, there is a clear focus of this study, which was an understanding of the extent to which a NOS course, designed according to the conceptualization of PCK for teaching NOS, affects in-service science teachers' understanding and learning of NOS, and their orientations towards teaching it. However, there was not indicated an interesting problem which could be addressed by this study. Realistically, there was a clear gap in the literature and this study could be filling in this gap. However, the author used a new NOS instruction, which was based on PCK that supported in Hanuscin et al. (2011). Again, there was no clear rationale about why this methodology was chosen as a best approach. Also, the data analysis section needs to be more extended (i.e these kind of researches need interview) and be more clear in order to understand how were analyzed data related to participants' views of NOS and orientations towards to teaching NOS.

Hanuscin (2013) explored what are the nature and significance of critical incidents to the development of a prospective teacher's PCK for NOS through an in-depth examination of the critical incidents in an elementary teacher candidate's experiences learning to teach NOS during her transition for the science methods course to student teaching. The author indicated that although teachers have understanding of NOS consistent with current reforms, they generally do not teach these ideas, or are less successful when they teach NOS. This study was theoretically framed by Magnusson et al.'s (1999) model which consists of five interacting components: (a) orientations toward science teaching, (b) knowledge and beliefs about science curriculum (goals and objectives/curriculum and materials), (c) knowledge and beliefs about students' understanding of specific science topics (prerequisite knowledge and student misconceptions), (d) knowledge and beliefs about assessment in science (dimensions of science learning to assess and knowledge of methods of assessment), and (e) knowledge and beliefs about instructional strategies for teaching science (topic-specific activities, e.g., activities for teaching photosynthesis; as well as subject-specific strategies, e.g., inquiry). Their model can be used to conceptualize PCK for NOS; for example, teachers' PCK for NOS would include knowledge of student misconceptions about NOS and of instructional strategies (e.g., explicit-and-reflective instruction) to address those ideas.

The author tried to answer the research question by showing critical incidents, which can play a vital role in developing PCK as teachers reflect on their teaching and learning experiences. Jane, the prospective teacher of focus, enrolled in the elementary science method course taught by the author. Her husband was a doctoral student in biological sciences, so Jane was familiar with scientists and scientific work and was enthusiastic about teaching science. Jane entered the course with a relatively strong knowledge of NOS in comparison to her undergraduate classmates, however the author did not talk about how was her understanding of NOS determined. During the methods course Jane read practitioner literature about NOS and how to teach NOS, participated as a learner in model lessons that addressed NOS, responded to classroom-based NOS assessments, and developed her own lesson plan that incorporated NOS objectives. Though she was concurrently enrolled in a field experience at a local elementary school, Jane did not observe her host teacher teaching about NOS, nor did she have an opportunity to teach her own lessons about NOS during that time. Following the course, Jane indicated a desire to gain experience teaching science, and NOS specifically, and volunteered to co-facilitate a weeklong summer science outreach program for elementary students under the mentorship of the author. This program had an explicit emphasis on NOS and inquiry, and (unlike her previous field experience) provided Jane an opportunity to put into practice what she had learned in the methods course with the support of her instructor. The mentor–mentee relationship between the author and Jane continued throughout Jane's student teaching experience the following year.

Narrative inquiry provided a methodological framework for this case study, which utilized 'critical incident' vignettes to examine key experiences in the development of Jane's PCK for NOS. The author assembled a 'critical incident file' that included the following data sources: (1) artifacts from Jane's learning about NOS from the science methods course, (2) lesson plans and instructional materials Jane utilized in the summer program and student teaching, (3) records of their ongoing email correspondence, (4) field-notes from collegial conversations in which they discussed problems of practice related to teaching NOS, and (5) Jane's reflection on her PCK for NOS following her student teaching experiences using the Content Representation Tool. The contents of this file were systematically reviewed and re-read, allowing for identification of particular comments, episodes, and ideas that were foregrounded or referenced repeatedly over time in Jane's experiences. The file was then organized into categories by Jane based on what she felt were key transitions in her learning to teach NOS. Through this process, a series of ten potential critical incidents were identified. Each of the ten incidents was then discussed in semi-structured interviews using 'thinking strategies' to probe the meaning of these incidents to Jane, and to determine their significance from her perspective. Through this process, mentor and mentee narrowed the list to four incidents, representing key experiences, contexts, and points in time during which Jane developed her understanding of how to teach NOS.

The four vignettes provide Jane's firsthand account of incidents she perceived as 'critical' in terms of their significance to her learning to teach NOS. Each vignette is followed by a researcher commentary that further analyzes and interprets the vignette from the perspective of PCK for NOS. The first vignette was "white men in lab coats?" in this vignette Jane realizes how others view science (science is a human endeavor), and resolves to address misperceptions among her students. At this point, she formulates a rationale for teaching NOS. According to the author, this vignette was an element of PCK, which is orientation toward science teaching. The second vignette was called "just like a scientist." In this vignette, Jane confronts a difficult moment while teaching a summer science program, but with the help of her mentor avoids "falling back" on ways to teach science that are easier, but that she feels misrepresent NOS. Jane makes a commitment to epistemological consistency between her ideas about NOS and her teaching. This vignette was an element of PCK, which is knowledge of instructional strategies; knowledge of assessment; knowledge of learners. The third vignette was called “When experiments don’t work.” In this vignette, during student teaching, Jane recognizes the same misconception among her students that she encountered while teaching the summer program. Since she attunes to this, it becomes a teachable moment where she explicitly establishes norms of science in her classroom. It is apparently suggested that student ideas about NOS develops her knowledge of learners. This vignette was an element of PCK which is knowledge of learners; knowledge of curriculum. The fourth vignette was “the scientific method.” In this vignette, Jane reacts to recognizing a myth perpetuated in her curriculum materials regarding the scientific method- and dares to teach the lesson differently. Jane’s experience demonstrates how teaching NOS can be an act of rebellion when the mandated curriculum does not effectively support NOS instruction. This vignette was an element of PCK, which is knowledge of curriculum; and knowledge of learners.

This study reaffirms the difficulty that teacher educators face in preparing future teachers to be able to help their students develop an understanding of NOS even though a person has an informed understanding of NOS. By examining a prospective teachers’ PCK for NOS, this study sheds light on potential source of PCK within teacher preparation, the interplay between the various component knowledge bases comprising PCK, and barriers and supports that impacted the development of her PCK. Overall, there was a clear focus for the study and the problem indicated a gap in the literature. The author clearly describes the methodology, and the theoretical framework, which was based on the study of Magnusson et al. (1999). However, there are many PCK models (i.e Grossman, 1990), which are used by the researchers. The author could explain the readers why this framework is the most appropriate one. The one of the most strength of this study is that the author clearly describes implications for teaching science and researching in science education.

One of the very latest attempts was conducted by Wabeh and Abd-El Khalick (2014), they assessed the influence of an integrated NOS instructional intervention on in-service secondary science teachers' understandings, retention of those understandings, and their NOS instructional planning and practices. Also they tried to find out possible factors that mediated the translation of teachers' NOS understandings into practice. Four research questions guided the study: (1) what is the impact of the integrated NOS intervention on participant teachers' understandings of NOS and the retention of these understandings? (2) What is the impact of the integrated NOS intervention on teachers' instructional planning and practices related to NOS? (3) What factors mediate the translation of teachers' NOS understandings into instructional practice? (4) What specific attributes of teachers' NOS understandings mediate, or interact with factors that mediate, such translation?

The study was conducted in two phases. The first phase was implemented with 19 participants in the form of a six-week, 36 contact hours, NOS-dedicated, teacher professional development summer course. A pretest, posttest, delayed-test, single-group design was used to assess the intervention's impact on participants' NOS understandings and the retention of these understandings. The second phase entailed observing a subsample of 6 participant teachers as they attempted to address NOS instructionally in their classrooms. A comparative, multiple case-study approach was used in this second phase to examine the impact of the course on teachers' NOS planning and instruction, as well as elucidating the factors that mediated the translation of their NOS understandings into practice.

All participants were administrated VNOS-C at the beginning and conclusion of the course. Sixteen of the nineteen participants filled out the survey five months later as a delayed assessment. Each VNOS-C administration was coupled with individual follow-up semi-structured interviews with a subsample of four randomly selected participants. Questionnaire and interview data were used to assess the impact of the NOS course on participants' NOS understandings and the retention of these understandings. The NOS course was planned and organized by covering and focusing on a set of NOS aspects including the empirical, inferential, tentative, creative, and theory-laden NOS; the nature of scientific theories and laws; multiple scientific methods; and the social and cultural embeddedness of the scientific enterprise. The researchers choose explicit-reflective NOS instruction in learning as conceptual change approach. During the course, participants were introduced to the science education community's perspective on the target NOS aspects through a set of seven generic activities. At the end of the description about NOS course, the authors superficially mentioned that integrated pedagogical approach and several instructional elements have been used to help participants to effectively teach about NOS in their classroom. However, there is not enough information about how to integrate PCK components into explicit/reflective NOS course.

For the second phase of this study, six randomly selected participants attended unit planning session. The unit plans and transcripts of planning meetings were used to assess the impact of the NOS course on participants' instructional planning related to NOS. After this session, these six participants were randomly split into two groups. The first group taught their units without any support or intervention from the researchers. On the other hand, the second group taught their units with full support from the researchers. During this phase II, the primary researcher observed and audiotaped all six teachers' planned sessions and kept detailed field notes, as well as a reflective personal log that was used to document any teacher researcher interactions.

The researchers comprised the all data in three phases. In the first section of the analysis, the authors said that the pretest, posttest, and delayed test VNOS-C responses and corresponding interview transcripts were analyzed to generate profiles of participants' conceptions of NOS at the outset of the study. At this stage, participants NOS views were categorized as naïve, partially informed, or informed with regard to each of the eight target NOS aspects. However, they did not explain how they decided participants' views of three categories. They should have clear rationale or kind of rubric to support their decisions related to participants' understanding of targeted NOS aspects.

The researchers focused on research question 2 in the second phase of the analysis. Analyses focused on the extent to which teachers were successful in articulating NOS related instructional outcomes in their plans. They coded participants' works and the data related to their instructional plans. The codes are "challenge", "success", "disconnection", and "S&S". these codes were enhanced from the analysis of first research question. "Challenge" refers to any instance in which a participant faced difficulties teaching about target NOS aspects. In contracts, "success" refers to any instance in which a participant teacher effectively addressed NOS aspects during the instruction. “Disconnection” refers to instances in which a teacher used a generic or stand-alone activity to introduce students to NOS ideas. Lastly, “S&S” refers to scaffolds and supports provided by the teachers in response to teachers’ requests.

The third phase of the analysis focused on last two research questions. Classroom data for teachers in the supported group, along with their reflective diaries, as well as researcher field notes and personal log documenting all communications with teachers, were used to construct detailed profiles of teacher instructional enactments. Comparing instructional case profiles both within the supported group and across both supported and non-supported groups helped shed light on factors that mediated the translation of teachers’ NOS understandings into their practice, as well as specific attributes of these understandings that mediated, or interacted with factors that mediate, such translation.

The findings of the study showed that explicit/reflective NOS instruction was effective for participants to improve their understanding of NOS. As similar to recent literature on teachers’ view of NOS, the participants had naïve understanding of NOS before the intervention. After the explicit/reflective NOS instruction, they improved their understanding of almost all targeted aspects of NOS. However, participants did not develop their understanding of theory-laden, multiple scientific methods, and theory and law aspects of NOS. Unlike the results from those reported by the Akerson et al. (2005), participants in this study retained their views of NOS five months following to conclusion of the course.

The most valuable finding of this study was the impact of the intervention on participants’ NOS instructional planning and practices. In the period of the instructional planning, almost all lesson plans featured explicit learning objectives focused on the empirical, inferential, and tentative NOS, as well as the social and cultural embeddedness of science. Participant groups were less successful in developing learning objectives related to the theory-laden and creative NOS, and the nature of theories and laws. No plans addressed the multiple scientific methods. As similar to other researchers' works (i.e. Schwartz & Lederman, 2002), these findings clearly represent that teachers were away from planning to teach about NOS aspects that were more challenging for them, namely, the nature of theories and laws, theory-laden NOS, and multiple scientific methods.

For the phase II, six teachers were randomly selected for the instructional practices, and they faced three challenges during the instructional design. The first was related to teachers' depth of understanding of their content knowledge; especially as such understandings pertain to the (historical) development of science concepts and constructs. The second challenge related to participants' pedagogical expertise pertaining to inquiry teaching. In their instructional practice, teachers mostly enacted 'inquiry' as teacher-directed, confirmatory 'hands-on' activities; an approach emphasized in their science textbooks and many of their professional development programs. The third challenge related to participants' understanding of NOS.

Based on these results, the authors generated factors that mediated the translation of teachers' NOS understandings into instructional practice included (a) depth of science content understandings, (b) assessing, and monitoring changes in, students' NOS conceptions, (c) pedagogical expertise pertaining to enacting student-centered and inquiry teaching, (d) availability of, and proficiency with locating and/or modifying, NOS-related instructional resources, and (e) the nature and attributes of teachers' NOS understandings.

Importantly, attributes of teachers' NOS understandings played a central role in the translation of NOS conceptions into practice, and interacted with some of the other mediating factors to either facilitate or hinder such translation.

In conclusion, the explicit/reflective NOS instruction was effective in enabling them to successfully teach about the empirical, tentative, social-cultural, and inferential NOS. However, the course was less effective in this regard especially in relation to the multiple scientific methods, nature of theories and laws, and theory-laden NOS. participants generally were not able to achieve moderate to high transfer of their newly acquired NOS understandings into instructional practice when it came to novel science contexts, content areas, or topics. Translation was mediated even in the case of NOS aspects for which teachers had articulate and informed 'understandings'.

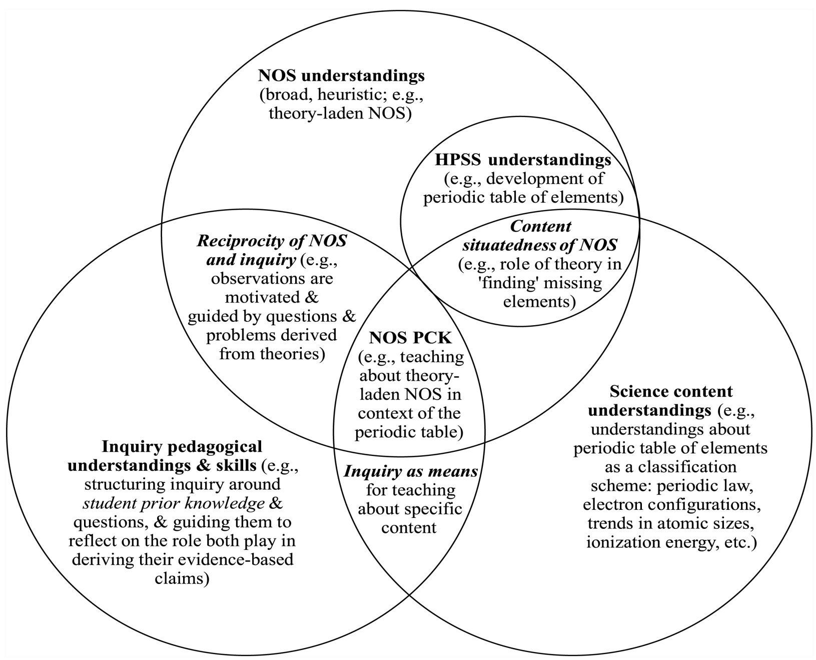

Figure 8. PCK for teaching about NOS in content-rich contexts

Wabeh and Abd-El Khalick's study was fit nicely into Shulmans' overall model of PCK. The model suggests that effective teaching about a dimension of NOS in content-rich contexts entails an amalgam in Shulman's (1986, 1987) sense of integrated understandings enabling the design and delivery of instruction adjusted for particular contexts, including specific learners and subject matters- with several sources of knowledge and set of skills which clearly shown in Figure 8, including: (a) broad heuristic understandings of the target NOS dimension embedded in some HPSS context, (b) deep understandings of the target science content, (c) situated understandings of that NOS dimension in relation to the target science content, which derives from knowledge of associated HPSS narrative(s) for central science concepts in the domain, and (d) understandings and skills needed to enact student-centered inquiry learning environments, including attention to student prior knowledge and the ability to engage students with inquiries that help them build understandings of the target science domain.

Overall, the study has a clear focus and rationale to addresses the problem that they stated. The theoretical framework, data collection, and data analysis were appropriate, coherent, complete and aligned with the research questions. All arguments and interpretations supported by the data and linked not comprehensively to prior literature because they also ignored prior PCK for NOS models such as Schwartz and Lederman, 2002. The one criticism is that it is not really clear how the authors integrated PCK components into their explicit/reflective NOS instruction. Another critic is that how to analyze data regarding to research question 1. The authors said that they categorized as naïve, partially informed, or informed views regard to eight targeted aspects of NOS, but it is not clear that how did they decide participants' views of NOS into these three categories. There is no rationale or kind of a rubric to categorize his or her understandings into three categories.

One of the interesting studies was done by Krajewski and Schwartz (2014). It was an action research study, and they tried to find out one teacher's journey of developing PCK for NOS as she worked to embed NOS into daily instruction. Also, they sought to identify challenges and successes in learning to teach NOS. The specific questions that guided this participatory action research study were: (1) how can an explicit-reflective approach of teaching NOS be incorporated into daily planning and instruction of non-major undergraduate biology curriculum? (2) What are challenges and facilitating factors that assist an experienced teacher in embedding NOS within daily instruction? According to the authors, this action research may offer new insight into beneficial techniques and instructional strategies needed to assist inservice teachers as they develop PCK for NOS by making connections within content while still explicitly teaching NOS.

The main participant in this action research study was the teacher- action researcher, Sarah; a college biology educator who has taught general biology for fifteen years. Action research methodology often focuses on one's own work within his/her classroom. This study was conducted in two semesters within an introductory, undergraduate, biology course. This action research was designed using four stages; (a) develop a plan of action to improve what is happening, (b) act on the plan, (c) observe the affects of the plan, (d) reflect on these affects.

There were two data sources including the teacher's lesson plans for answering research question 1, and her reflective journal entries for answering research question 2. They used inductive thematic analysis in order to pulled out emergent themes.

According to analysis of lesson plans, NOS tenets that were successfully embedded into instruction were documented throughout both semesters. However, in the first semester, Sarah had missed some opportunities to include and use some NOS tenets, like socio-cultural issue, and subjectivity of science. On the other hand, in the second semester, an increase was seen in development in her PCK for NOS, and using the tenets in her lesson plans.

For the research question 2, Sarah's journal entries were analyzed in order to answer what are the challenges and facilitating factors that assisted in embedding NOS within daily instruction. According to thematic analysis of the journal entries, authors identified four facilitating factors that assisted in successfully embedding NOS into daily instruction. These are (1) resources, (2) reflection, (3) successes, and (4) the process of action research. The authors clearly explained all factors and gave supporting examples of how these factors affected her success. Related to "resources", Sarah used different resources as she sought how to embed NOS into her science curriculum. According to her, these resources helped her to effectively teach them and to draw connections to other biology subject matter. Related to "reflection", Sarah wrote reflection before and after of every single lesson. She argued that this provided the opportunity to document and reflect on how the plan to embed NOS was carried out, how it was successful, and what changes may have been made to the lesson plan or would be recommended for next semester or next class periods. Analysis showed that the second semester journals reported NOS instruction as more naturally portrayed with greater confidence. Contrary to the first semester journals that were plagued with comments regarding how difficult it is to embed NOS, her second semester comments became repetitive with positive remarks regarding how much easier NOS was embedded into the curriculum. Related to factor of "successes" increased confidence in ability to teach NOS, she believed that success led to more success. Her confidence increased and anxiety regarding incorporation of NOS lessened when she saw her teaching was successful. Success is a natural motivation for most teachers like Sarah. Related to factor of “action research”, she argued that participating in action research made her more aware of her own teaching practices, and empowered her to change by pushing her comfort zone of teaching science and embedding NOS into it.

In conclusion, the authors recommended a proposed model by using their action research study and integrated with findings from others (Hanuscin, 2013, Schwartz & Lederman, 2002). In this sense, the authors argued that the “knowledge of NOS” domain needs to grow and shift to overlap with “pedagogical knowledge” and “subject matter knowledge”, illustrating knowledge of connections across all three domains. Schwartz & Lederman (2002) proposed this overlap to represent PCK for NOS. The authors also pointed out here that the teacher’s orientations toward science teaching might influence this process (Hanuscin, 2013). Hanuscin (2013) provided further elaboration by demonstrating the need for connections to knowledge of the curriculum, assessments, the context, and the learner. As suggested by the results, the process of growing and shifting knowledge domains and orientations may be facilitated through action research. They also recommended that action research as one way to accomplish the goal of teaching both inservice and preservice teachers to embed NOS into their instruction.

Only criticizing of this study is that there was no evidence about Sarah’s knowledge of learners, knowledge of curriculum, knowledge of assessment, and orientation toward teaching science. However, the authors pointed out PCK for any subject matter including NOS needs to think of these dimensions. I need to see more evidence about Sarah's PCK for NOS as presented in the figure above. Apart from that, there was a clear focus for the study. The authors clearly describe the methodology of action research study, and why it is a valuable way to use in science education, especially developing PCK for NOS.

Summary of Literature Review

Although the focus of this literature review is preservice science teachers' PCK for NOS and SI, researchers mostly used inservice teachers as a subject to explore PCK for NOS. For this reason, discussions will be placed around inservice science teachers' PCK for NOS and SI. However, it should not be forgotten that there is a gap, which needs to be studied with preservice science teachers' PCK for NOS and SI. Overall, the studies critically analyzed above indicated that teachers with informed views of NOS do not necessarily evidence these views in their practice (Faikhamta, 2013; Hanuscin, 2013; Hanuscin et al., 2010; Wahbeh & Abd-El-Khalick, 2014). Researchers investigate how these views are presented during planning and instruction and to identify critical influences on this translation.

While teachers were supported with NOS instruction as part of their preparation, they, in some degree, had a hard time for translation of their views into the practice. These difficulties included classroom management issues, knowledge of subject matter, pedagogical knowledge, knowledge of assessment, concerns and beliefs regarding students, self-efficacy regarding NOS instruction, and the pressure to cover content (Hanuscin et al., 2010; Wahbeh & Abd-El-Khalick, 2014).

One of the most important factors that appears to play a role in the translation of NOS and NOSI knowledge into practice is a teacher's subject matter knowledge and realizing how to ingrate NOS and NOSI into a subject (Faikhamta, 2013; Hanuscin, 2013; Hanusicn et al., 2010; Krajewski & Schwartz, 2014; Wabeh & Abd-El- Khalick, 2014) as Schwartz and Lederman (2002) investigated that teachers' varying degrees of subject matter knowledge and conceptions of NOS impacted their efforts. In general, teachers need to develop PCK for teaching NOS and NOSI just as they must for any subject matter, in addition to possessing a belief in its importance and having the intent to teach it.

Also, it is clear from the dominance of evidence presented is that teachers' subject matter knowledge are not necessarily translated into their classroom practice, nor are their understandings of NOS and SI. While many factors hinder this translation in regard to teachers' understanding, many of these (e.g., classroom management and organization issues, unfamiliarity with the curriculum, lack of understanding of NOS and SI) appear to be a function of the challenges faced by inservice teachers during their induction to the profession. Teachers, in effect, need PCK for NOS and SI, which encapsulates knowledge of NOS and SI, pedagogical knowledge regarding the teaching and assessing of NOS and SI, knowledge of the "traditional" subject matter, and how these domains interact, overlap, and modify each other. In specific, when the improvement of students' conceptions of NOS and SI is a targeted instructional objective, it is imperative that teachers explicitly draw attention to the relevant aspects o f NOS and SI reflected into classroom practice. In other words, teachers must realize all factors that affect their practicing of teaching NOS. Thus, development of preservice teachers' PCK for NOS/SI might the one of the most important issues in preparation of preservice science teacher education.

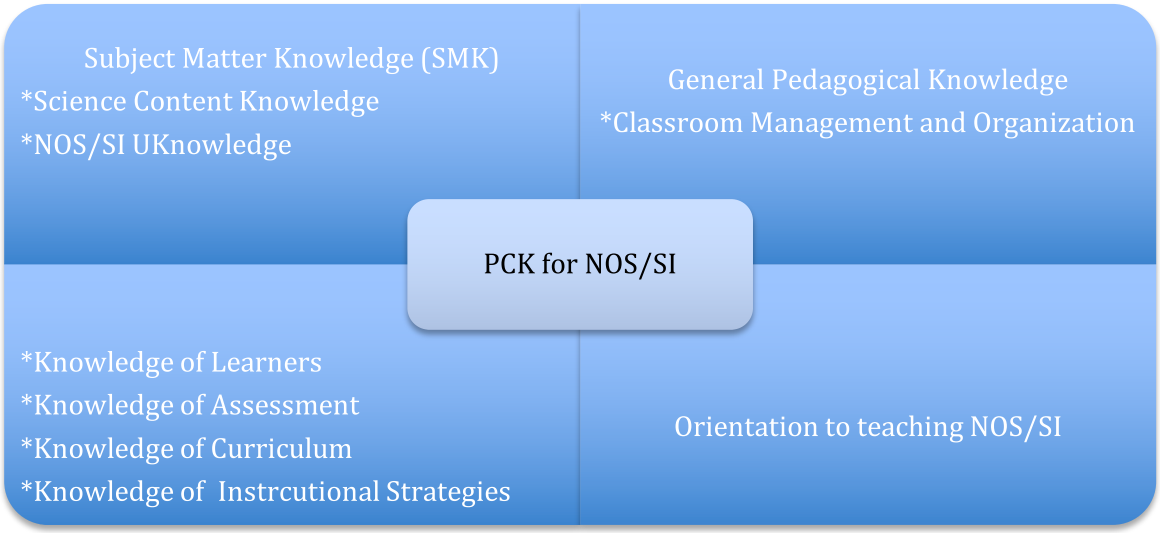

Figure 9. A purposed model of PCK for NOS/SI from Existing Literature

Over 70 years researchers have attempted to answer what is NOS or NOSI; and explore what do students, teachers, educators, or even philosophers think about it. Based on these discussions, they have suggested that there is a need to develop people's understanding of NOS and SI in order to raise scientifically literate people as a big goal of science education community all around the world. Thus, researchers argued different instructions of NOS and SI for teaching it effectively. One of the popular instruction method is explicit/reflective NOS and SI teaching. However, teachers had a hard time to integrate NOS and SI into a science subject even though they use explicit/reflective instruction. For this reason, there is a need to explore the factors that affect teachers' NOS instruction when translating their NOS/SI understandings into practice. As provided figure above, PCK for NOS/SI needs to come up with some components, which include general pedagogical knowledge, subject matter knowledge for NOS/SI and a science content, classroom managements and organization, and orientation towards teaching NOS. Teacher preparation programs specifically must be organized by realizing these components of PCK for NOS/SI. From the studies about PCK for NOS/SI, the important thing is that if a teacher does have an informed understanding of NOS and SI, it does not have to mean that he/she teaches it effectively. However, if a teacher does not have an informed view of NOS/SI, he/she definitely cannot teach it effectively. Thus, teachers at least must have an informed understanding of each of the components of PCK for NOS/SI explained above.

The characteristics of teachers' understandings for NOS and SI could provide additional insight into the challenges encountered when attempting to transform informed views of NOS and SI into classroom practice. When seeking to examine the translation of these views for NOS and SI it would appear most efficacious, in light of the aforementioned research, to examine (a) preservice teachers; (b) experienced teachers (i.e., at least five years experience); (c) teachers with adequate subject matter knowledge; (d) teachers who feel sufficiently unconstrained by their curriculum; (e) teachers with informed views of NOS and SI; (f) those who have sufficient preparation geared toward the development of their pedagogical content knowledge for teaching NOS and SI; and (g) teachers who value NOS and SI as instructional outcomes.

CHAPTER III

METHODOLOGY

Introduction

This is an exploratory multiple case study of participants' experiences and developments during the Experiencing Research for Teaching Science (ExpeRTS) program. This experience is for Western Michigan University undergraduate students, who are interested in pursuing a teaching profession in chemistry, biological sciences, physics, or geosciences. The main purpose of the current study is to discern preservice science teachers' understanding for nature of science (NOS) and scientific inquiry (SI) and determine how they translate these views communicated through teachers' classroom practice. The overarching research questions guiding this study include the following:

1) How does content knowledge of NOS and NOSI develop over time for preservice teachers during the ExpeRTS program?

2) How does pedagogical knowledge for NOS and NOSI describe for preservice teachers during the ExpeRTS program?

3) What factors mediate preservice teachers' abilities and teaching experiences to enact their PCK for NOS and NOSI?

The main component of the study necessitates a multiple case study design, similar to past research on experience science teachers' subject matter knowledge (e.g., Gess-Newsome & Lederman, 1995; Lederman, Gess-Newsome, & Latz, 1994). This study requires a case study method due the nature of the research questions, which seek a better, richer understanding of and insight into preservice teachers' PCK for NOS and SI, and its translation to their teaching practice. Case study methodology is appropriate for this study for some reasons. As Stake (1995) pointed out, when something is not sufficiently understood, like how PCK for NOS and SI is translated into practice, then case study research can and should be used. Case studies are useful when the interest is in the discovery over confirmation and in gaining "an in-depth understanding" (Merriam, 1998, p. 19). PCK for NOS and SI is a developed theory that needs clarification and greater understanding of its use in practice (Abell, 2007). For case studies, "the goal is to expand and generalize theories" (Yin, 1994, p. 10). They can be used in building a theory, providing insights into it, testing it, and/or adding to its application. Clarification of PCK and adding to its application is what is needed to strengthen the theory of PCK and make it useful to teachers and teacher educators (Abell, 2007; Kind, 2009). The teaching process is also complicated and embedded within the context of the students, classroom, and school environment. Since the context is part of the understanding, case study research is necessary (Merriam, 1998; Stake, 1995; Yin, 1994). Beginning to understand how PCK translates into practice requires a case study approach because of the subject matter, the desire to understand a process, PCK, and the contextual nature of teaching practice.

All data was collected throughout multiple ways. Using multiple methods of data collection allows for corroboration of patterns found in the data, which adds credibility to the results. Multiple methods can also help to make up for the weakness of having a small sample size in utilizing case studies (Cresswell, 2007). The details regarding data collection and analysis are described in detail in the following sections.

Also, teachers' views of NOS and NOSI as evaluated by traditional, open-ended instruments were compared with their views communicated through their understandings.

Regarding the "traditional" evaluation of teachers' views of NOS and NOSI, the Views of Nature of Science Questionnaire (VNOS-270; Lederman et al., 2002) and Views of Scientific Inquiry Questionnaire (VOSI; Schwartz et al., 2008) were used, respectively, to generate rich profiles of each participant between and within a variety of targeted aspects. In addition, Content Representation (CoRe; Loughran et al., 2004; 2006), and Science Teachers' Pedagogical Discontentment Survey (Southerland et al., 2012) were used to understand the participants' PCK for NOS and SI. Details regarding each instrument are provided in the sections that follow.

Participants and Sampling Methods

The participants were recruited from those who participate in the ExpeRTS program through class announcements, e-mail messages, and poster/flyer information distributed on campus. The researcher distributed a consent form to all potential participants. The researcher used the oral scripts for recruiting participants. First, the students who are interested in the project were shown the consent form. They were asked to read the consent form and if they had any questions, the researcher addressed any questions about the use of student data for the research. If after reading the consent form from the students who are agreeable, the students signed and returned the informed consent form to the researcher, who sealed the forms in an envelope (HSIRB Approval form is provided in Appendix P).

Criteria for Participant Selection

This study specifically focuses on how PCK for NOS and NOSI is described over time for preservice teachers during the ExpeRTS program. Thus, participants purposefully selected as the potential cases in order to demonstrate successful development during the program. At the end of the program, after all data was collected, the participants were recruited among those who participated in this program. Following assumptions are considered as the criteria based on the researchers' observations and initial analysis.

- Preservice teachers, having improved their understanding of NOS and NOSI during the professional development, have sufficient subject matter knowledge of NOS and NOSI to teach it.
- Participants have sufficient PCK for NOS and NOSI.
- Participants focus on NOS and NOSI aspects on their lesson plans and two-weeks science teaching camp.

Rose and Charlie (These names are pseudonyms) were purposefully selected based on the above criteria for participation on this study. At the beginning of the program, they had informed views about NOS and NOSI, and they continued to program as a partner. Rose and Charlie developed lesson plans and taught those lessons on their teaching practices together. The data related to first research question and second research question were collected individually which were analyzed to present their individual views of NOS and NOSI, and their PCK for NOS and NOSI. The data related to third research question were collected thorough their partner efforts, including teaching as a partner, preparing lesson plans, and teaching observations.

Rose was 24 years old female senior student whose major was elementary science teaching education, and her minor was chemistry. On the other hand, Charlie was 25 years old male senior student whose major was chemistry, and minor was biology. Both Rose and Charlie took the same biology course which was given by the same instructor who emphasized on NOS and NOSI, before the ExpeRTS program started. One of the most important differences between Rose and Charlie was their career goals. Charlie emphasized that he had a strong science background, and he would like to be a college professor. On the other hand, Rose would like to be an elementary science teacher. In addition, their course experiences in college were also different. Charlie mostly took courses from the fields of chemistry and biology. Rose took more chemistry education, and general teaching method courses.

Context of the Study

The ExpeRTS elements and their fit within the typical undergraduate education program in the U.S are depicted in Figure 10. The three elements are (1) a mentored and authentic science research experience, (2) support and instructions for translating the experience into teaching practice, and (3) mentored teaching practice. Following the second or third year of undergraduate preparation, the selected ExpeRTS Fellows, Rose and Charlie, began their 13-month experience.

Science Research Experience: The first experience for Rose and Charlie was a 10-week full-time summer research internship. The science faculty who serve as mentors represent biological sciences, and chemistry. The faculty members' diverse backgrounds created an ideal setting for demonstrating the importance of communication among various disciplines and the value of cross-disciplinary perspectives to single problems. Rose involved in a project in biochemistry. Her research title was "*Exploring Antimicrobial Properties of Metal Nanoparticles".* Charlie involved in a project in biology. His research title was "*The effects of pioglitazone on C6 oligodendrocyte-like cells treated with alpha-synuclein*". Rose and Charlie conducted a research project with an emphasis on student ownership and community. They were culminated the internship with an interactive poster session. They were also encouraged to present their research at other science conferences, and modest funds are available for travel support. During the summer experience, they also observed former cohort's teaching during the 2-weeks 8th grade science camp. They observed and reflected upon the instructional strategies being used (inquiry and direct). The following summer, the fellows were the camp instructors (see the section of "teaching practices").

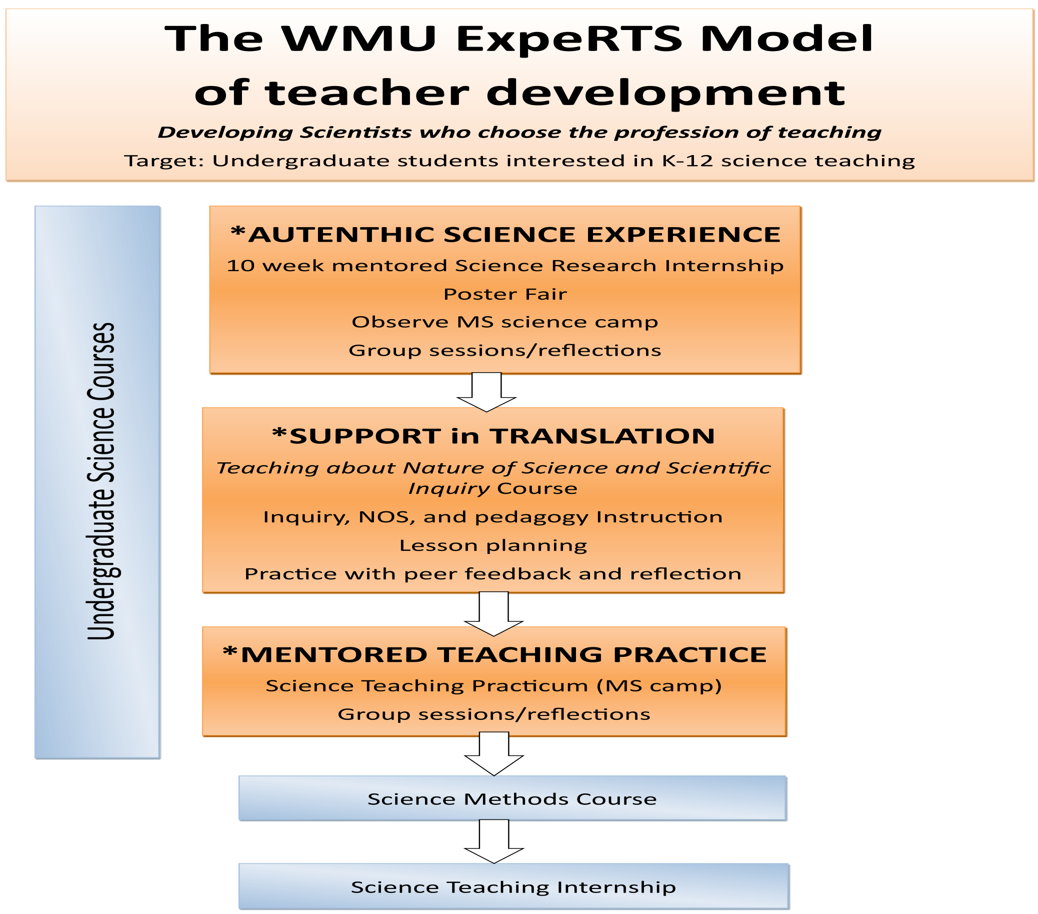

Figure 10[1]. The ExpeRTS Model

[1] The orange* boxes are elements of the ExpeRTS model. The blue boxes are elements of the regular teacher education program.

Support in Translation: Explicit/reflective instruction on NOS, NOSI, and inquiry pedagogy. Throughout the 10-week internship, the Fellows participated in group seminars and instructional sessions that focus on NOS, NOSI, and inquiry teaching. They also attended seminars given by the research mentors. They were prompted to compare their own experiences with these other settings. There was also four, 2-hour group instructional sessions during the Fall Semester. Group sessions were served as a venue for (1) reporting/updating research progress; (2) instruction, guided reflection, and peer sharing about scientific inquiry as represented within authentic science contexts; and (3) explicit instruction about NOS and NOSI. Activities were adapted from Lederman and Abd-El-Khalick (1998) as well as additional lessons that demonstrated experimental and observational methods. During the following academic year (Spring semester), Fellows took a 3-credit hour course, "NOS and Inquiry," designed and taught by one of the project PIs. This was a practical application course involving lecture, laboratory activities, and discussions. The goal of the course was to explore connections between authentic scientific research and classroom science learning and teaching experiences that were appropriate for middle and secondary students. The course emphasized the themes of NOS, scientific inquiry, and pedagogical content knowledge as essential contexts for gaining meaningful understanding of traditional science subject matter. NOS and SI aspects were explicitly taught in this course, using instruction based on the following guidelines designed by considering the recommendations by Abd-El Khalick and Akerson (2004) in order to provide purposeful and planned opportunities to learn: (1) Goals and objectives for NOS were made explicit, (2) Instructions included experiences, concepts, and vocabulary that enabled students to consider NOS in an appropriate way,

(3) Discussions related science and classroom activities to aspects of NOS/SI and activities of scientists, (4) Questions fostered critical thinking and building of connections among aspects, (5) Individual reflections prompted students to formalize their ideas through guided personal reflections, (6) Group sharing provided opportunities for sharing of ideas and experiences (with the guidance of the teacher through focus questions and activities). As stated in the course syllabus: by the end of this course, students are able to;

- Develop conceptual knowledge of the nature of science and nature of scientific inquiry
- Develop pedagogical knowledge and abilities to teach science through inquiry; including using an explicit/reflective approach for NOS and inquiry, and using the Next Generation Science Standards.

References to several scientific articles (Lederman & Lederman 2004; McComas 2004; Schwartz, 2007) and a book (Chiappetta & Koballa, 2009) were included for students in order to provide a background that made the ideas present more contextual and embedded in scientific practice. Activities were adapted from Lederman and Abd-El-Khalick (1998), and Schwartz et al. (1999) as well as additional lessons that demonstrated NOS and SI aspects, and various investigate methods. The activities included the pattern cube, tube, fossils, tricky tracks, pictures, and mystery bones, which were designed to explicitly/reflectively help students develop appropriate conceptions of NOS and NOSI. They established a common basis of vocabulary and examples that were referred to throughout the semester. Also during this instruction period, student groups read about NOS and SI myths (McComas, 2004) and prepared a poster to explain an assigned myth and the accepted perspective (e.g. the myth of a single scientific method).

They also created group and individual concept maps of NOS themes. These experiences and class discussions offered opportunities for students to formally examined their personal conceptions. Peer sharing generated additional options to explore. Throughout the discussions and activities, examples and ideas from science were infused which were intended to enrich classroom discourse and support the notions present with instances from science. All classroom activities supported students' ability to create new knowledge from their own personal understandings of the world (connecting conceptual change). In these ways, the NOS and NOSI instruction was explicit (purposeful attention to specific NOS aspects in conjunction with learner experience) and reflective (learner reflection about own and others' understanding of NOS aspects; consideration of how conceptions compare with each other and experiences).

For example, the tube activity (Lederman & Abd-El-Khalick, 1998) was provided students with experiences similar to real scientists. Students examined the tube phenomena and attempted to explain how it works. They made observations, collected data, made inferences, and suggested hypotheses in order to explain their data. Next, based on the hypotheses, students made models and tested them. Based on their tests, they judged whether their models were appropriate or not. The tube activity was used to convey to students' conceptions of many aspects of NOS including the distinction between observation and inferences, that science is partly a product of human inferences, imagination, and creativity, scientific knowledge is tentative, and science is empirically based. (An example of the explicit/reflective instruction during the introductory series is provided in Appendix K). The other targeted aspects of NOS and SI were covered and taught with activities and discussions in a similar way to the tube activity example. This course extended the NOS, NOSI, and inquiry teaching experiences and reflections. Fellows designed and practiced science lessons that target these strategies.

Mentored Science Teaching Practice. The third element is a mentored teaching experience, 2-week teaching practicum. Fellows taught their science lessons during the two-week 8th grade summer camp (3 hours/day; 4 days/week). As explained above, the semester course provided opportunities for lesson planning and practice. During the course, each Fellow taught a 10-minute demonstration to the class. Then, based on their teaching interests, in groups of 2 or 3, Fellows taught an inquiry-based lesson to the class. All these practices were video recorded, and Fellows wrote a reflection after they watched their own teaching. Fellows choose a science topic, which included clear NGSS standards for 8th grades. The lesson was required to include their knowledge of a science concept, NOS, and NOSI. It was required to include at least one of NOS or NOSI aspect. With this microteaching in the class, each fellow with his/her partner designed four days lesson plans for summer camp. The researchers reviewed these lesson plans drafts, and Fellows revised their lesson plans based on the feedbacks given by the researchers. After they finalized their lesson plans, they were ready to teach these lessons on the two-weeks summer camp. During the camp, Fellows taught their lessons in the first week, and then second week, they re-taught the same lessons to different students. Each class had around 15-20 students. Each class session was video recorded for further analyses. Also, experienced middle school teachers mentored the teaching practicum. After each lesson of the camp, the mentor teachers gave the Fellows some feedbacks about their lessons in order to change or revise their lesson for next days. After Mentor-Fellows discussion, All

Fellows and mentors met and shared their days to others. Also, Fellows wrote a reflection after each day.

Data Collection

In order to answer the research questions and create a rich description of the case, data is collected in the form of open-ended surveys, interviews, observations, lesson plans, video materials, and teaching documents. These data sources are recommended for case study research (Merriam, 1998; Stake, 1995; Yin, 1994). One of the strengths of case study research is the fact that it uses many data sources, providing a rich database of information (Yin, 1994). According to Abell (2007), when measuring complex avenues of teaching, such as PCK, studies that "use multiple methods over an extended period of time provide researchers with a rich set of data from which to draw conclusions and make inferences" (p. 1123). Multiple data sources were used for several reasons. As Yin and Merriam both emphasized, the multiple sources of data inform other areas of data collection which allows for richer data. For example, some interview questions were asked based on what had been observed in the classroom to understand the teacher's motives for the action. Multiple data sources were also used to see if ideas are the same or hold true across space or other interactions (Stake, 1995). They also allowed for triangulation of the data, which improve the validity of the study (Yin, 1994).

As explained above, participants' targeted aspects of NOS and NOSI views were assessed in a pre/mid/post format with the Views of Nature of Science questionnaire [VNOS-270] (Lederman, Abd-El-Khalick, Bell & Schwartz, 2002), the Views of Scientific Inquiry questionnaire [VOSI-270] (Schwartz, Lederman, & Lederman, 2008), and follow-up interviews. These surveys were used as the most appropriate instruments in order to understand participants' views of NOS and NOSI because these open-ended instruments were compared with participants' views communicate through their understandings in order to generate rich profiles of each participant between and within a variety of targeted aspects. Related to participants' understanding of PCK for NOS and SI, Content Representation (CoRe; Loughran et al., 2004; 2006), and Science Teachers' Pedagogical Discontentment Survey (Southerland et al., 2012) were implemented. Each instrument was provided with follow-up interviews in order for understanding deeply. Details regarding each instrument are provided in the sections that follow. The whole chorology of data collection is illustrated below in Figure 11.

Data collection began at the beginning of the ExpeRTS program, using VNOS-270 and VOSI-270 questionnaires in order to understand participants' views of NOS and SI. After initial analysis of the questionnaires, follow-up interviews were used to clarify their understanding of NOS and SI before starting the program. During the first section of the program, participants were involved in science research and also observed former Fellows' teaching sessions.

Their reflections on classroom observations and their own research experience for each week were collected as additional data (Reflection protocols are provided in Appendix I). After their science research experience was done, VNOS-270, VOSI-270 and follow-up interviews were implemented as mid test to elicit any changes about their views of NOS and SI after the research experience. During the following semester, participants and the researcher met once a month for two hours. In those meeting sessions, NOS and SI aspects were explicitly taught by one of the PIs. Whole meetings were video recorded and observed by the researcher.

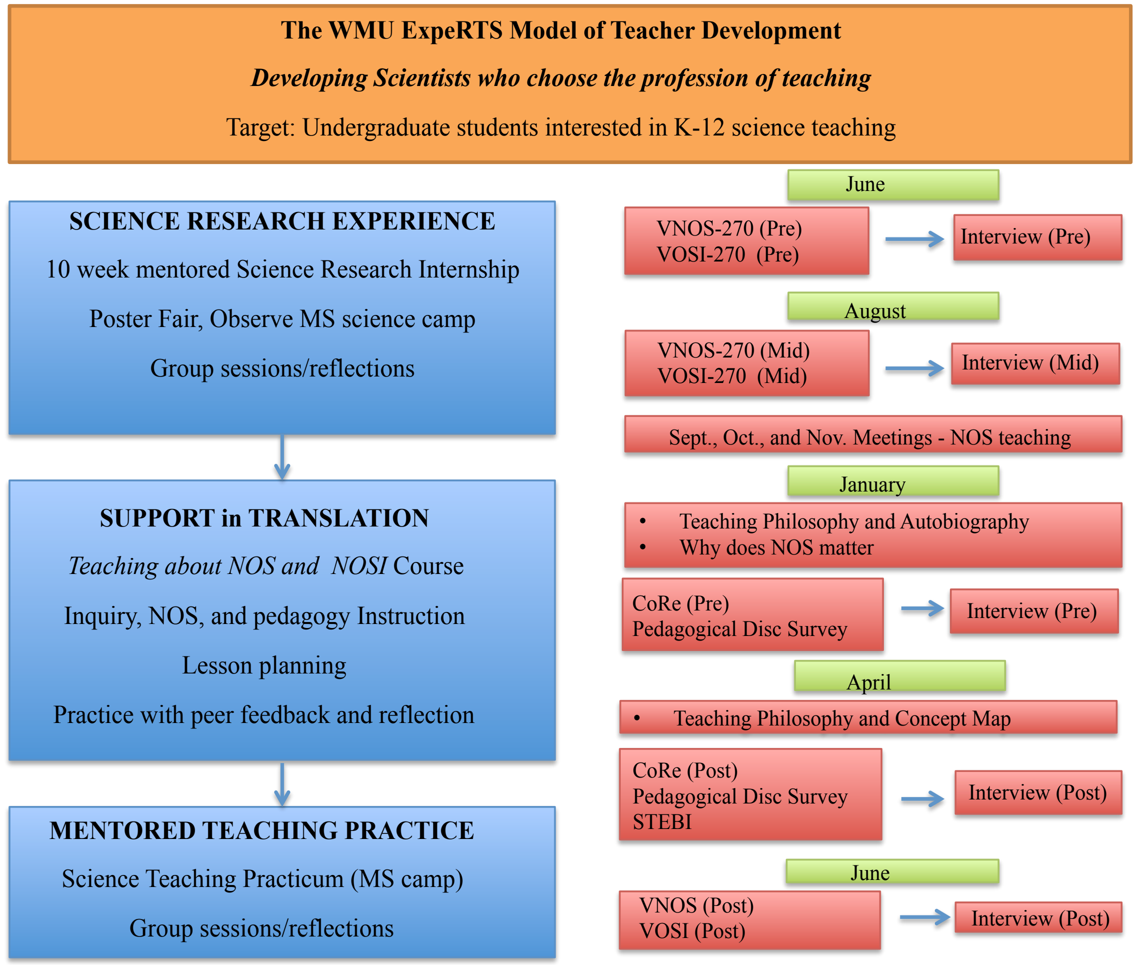

Figure 11. Chronology of Data Collection

Then, the spring semester, participants enrolled in a Teaching about NOS and NOSI Course. At the beginning of the course, CoRe and Science Pedagogical Discontentment Survey were used to understand participants' PCK for NOS and SI. Details about these surveys are provided in the next section. After the first analysis of these surveys, follow-up interviews were conducted. Also, participants were asked to write some essays on various topics, including "Teaching Philosophy," "Science Autobiography," and "Why does NOS matter." During the course all activities, classroom discussions, participants' demonstrations, and microteachings were video recorded, and participants were asked to write reflection essays about their teaching practices. Also, whole class sessions were observed by the researcher. Figure 12 shows what data was collected during the course. After the course, CoRe, Science Pedagogical Discontentment Survey, and follow-up interviews were implemented as a post test in order to understand changes to their PCK for NOS and SI during the course. Also, participants' lesson plans (both drafts and finals) for teaching science were collected as additional data.

During the summer, participants taught science lessons to 8th grade students during a two-weeks science camp. Whole lesson teachings were video recorded and observed by the researcher. Each day, the research participants were asked to to write a reflection essay about their own teaching (see Appendix J). After the two-week science camp, participants were asked to fill out the VNOS-270 and VOSI-270 questionnaires as posttest. In addition, exit interview was conducted in order to make sense whole 13-month program.

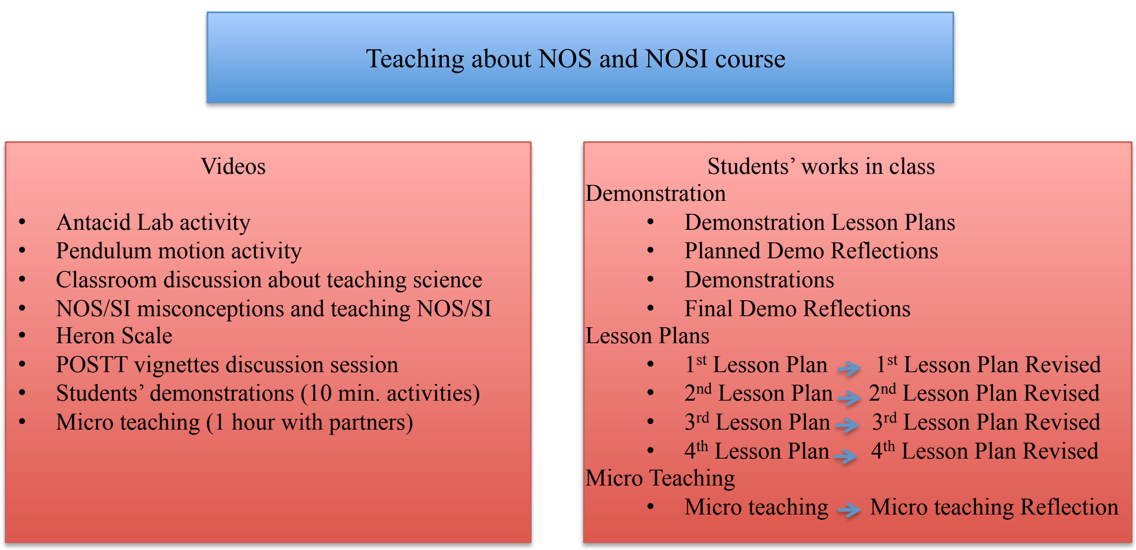

Figure 12. Data Collection during the Teaching about NOS and SI Course.

Data Sources

Questionnaires

Views of Nature of Science Questionnaire (VNOS-270)

The VNOS-270 consists of 7 open-ended questions designed to probe views of specific NOS aspects. The questionnaire had previously been validated for use with the intended participants (Lederman et al., 2002). The open-ended nature of the VNOS-270 allows respondents to use their own words and examples, without being forced into a choice and/or words being chosen for them. Respondents are asked, in general, to respond to each question as completely and clearly as possible, using examples when necessary. The VNOS aims to ascertain respondents' views on seven specific aspects of NOS, namely that (1) scientific knowledge is empirically based; (2) observations and inferences are qualitatively distinct; (3) scientific theories and scientific laws are different types of knowledge; (4) the generation of scientific knowledge requires human imagination and creativity; (5) scientific knowledge is theory-laden (i.e., influenced by scientists' prior knowledge, beliefs, training, expectations, etc.); (6) scientific knowledge both affects and is affected by the society and culture in which it is embedded; and (7) scientific knowledge, while reliable and durable, changes. Lederman et al. (2002) can be referenced for a more complete explication of these aspects and the development of the VNOS questionnaire in general (VNOS-270 questionnaire is provided in Appendix A).

Views of Scientific Inquiry Questionnaire (VOSI- 270)

The VOSI-270 consists of 5 open-ended questions designed to probe views of specific inquiry aspects include: a) questions guide investigations, b) multiple methods of scientific investigations, c) multiple purposes of scientific investigations, d) justification of scientific knowledge, e) recognition and handling of anomalous data, f) sources, roles of, and distinctions between data and evidence, and g) community of practice (VOSI-270 questionnaire is provided in Appendix B).

Content Representation Survey (CoRe)

CoRe (Loughran et al., 2004; 2006) is a way to elicit a teacher’s PCK along with a method to help develop a teacher’s PCK when used in an instructional setting. A CoRe consists of identifying the big ideas for a topic, and then for each big idea the following eight prompts are answered: (1) What you intend students to learn about this idea, (2) Why it is important for students, (3) What else you might know about this idea (that you don't intend students to know yet), (4) Difficulties/limitations connected with teaching this idea, (5) Knowledge about students' thinking which influences your teaching of this idea, (6) Other factors that influence your teaching of this idea, (7) Teaching procedures (and particular reasons for using these to engage with this idea), and (8) Specific ways of ascertaining students' understanding or confusion around this idea. Loughran et al. provide some examples of CoRe created by a group of "experienced, successful science teachers" (p 21), which they repeatedly claim are not meant to represent "the PCK for that topic" just provide example. (CoRe survey is provided in Appendix E)

What you intend the students to learn about this idea: This is the first attempt of a CoRe and is a starting point for the big ideas. Recent studies showed that experienced teachers have little struggling in being specific about what a particular group of students should be able to learn. However, teachers do not have enough in a given topic tend to be unsure what the students are capable of achieving. Thus, as a starting point in science teachers’ understanding of what matters in a particular content area and why, this prompt is very important and helpful.

Why it is important for students to know this: This prompt is important for understandings teachers' knowledge of science curriculum for a particular subject. Researchers suggested that for effective science teaching, teachers draw on their experience and knowledge of the given subject matter with that which they know to be relevant to students' everyday lives, so that they can create meaningful ways of encouraging students to grasp the essence of the ideas/concepts at hand.

What else you might know about this idea (that you don't intend students to know yet): Teachers, and mostly novice teachers, have a hard time to decide what should be included, and what should be excluded, in order to develop an understanding of a particular subject matter for students. Successful teachers have a sufficient knowledge about this prompt in order to handle difficulties or misconceptions might reduce students' learning.

Difficulties/limitations connected with teaching this idea: As recent researchers emphasized that teachers attempt to develop and eliminate potential difficulties, when teaching a particular topic. Even experience teachers struggle to identify, explain, and resolve the misconceptions and the limitations that students often have in a science classroom. This component of PCK helps teachers to develop and reconstruct students' existing knowledge and understanding of a particular topic.

Knowledge about students' thinking which influences your teaching of this idea: This prompt help teachers to make explicit to realize their own experience of learning about a particular topic which influence their thinking about their teaching. Experienced science teachers often make lesson plans and shape their teaching about students' commonly held ideas about the topic and how students respond to the topic. For the novice science teachers, this prompt is very hard to answer, but that is a very good starting point to think about their teaching, and their students' overall thinking about a science topic.

Other factors that influence your teaching of this idea: The aim of this prompt is help teachers to think about other possible affects which might influence their teaching. Teachers are supposed to think about their students as well as their general pedagogical knowledge in order to explore how these factors might influence to their approach and construct for teaching a particular subject matter.

Teaching procedures (and particular reasons for using these to engage with this idea): Teachers are supposed to talk about their activities, procedures, and strategies to teach a particular science topic. Teaching procedure is a critical point in that teachers select which procedures to use, when, how, and why in order to promote different aspects of learning. Also, teaching procedures is an important aspect of PCK because effective science teaching needs to choose successful teaching procedures that are appropriate and consistent with the intended learning outcomes and knowing not only how to use them, but why, under what changed circumstances, and being able to adjust and adapt them to meet the contextual needs (Loughran, 2006, p. 49).

Specific ways of ascertaining students' understanding or confusion around this idea: This prompt helps to explore how teachers assess their students' understanding or confusions. Teachers' approach for assessing a particular science topic is crucially important in order to understand different perspectives on the effectiveness of their teaching.

Science Teachers' Pedagogical Discontentment Survey

This questionnaire asks teachers to reflect upon their current science teaching and to think about the level of contentment and discontentment they hold about a number of science teaching practices. In this questionnaire, it is considered if teachers' performance of these practices helps them to reach their teaching goals. Too, it is also considered if their performance of these practices prevents them from reaching their teaching goals. It has 30 statements likert scale from one to five, which indicate teachers' level of discontentment in terms of their own science teaching. In others words, how discontentment are they currently with these aspects of their daily science teaching (The questionnaire is provided in Appendix F). This survey is classified into five categories: ability to teach all students science, science content knowledge, balancing depth versus breadth of instruction, implementing inquiry instruction, and assessing science learning.

Interviews

Follow-up Interviews

The follow-up interviews were implemented in a semi-structured format, using responses to the questionnaires including VNOS-270, VOSI-270, CoRe, and Science Teachers' Pedagogical Discontentment Survey. Typical questions were asked respondents to explain their answers, provide examples, or expand upon what they had written. The intent of the interviews was to clarify what the participants had written and gathered any supporting examples they might provide to further explain their ideas. Specific interview questions varied with each participant because questions depend on written survey responses. This protocol is as recommended by Lederman, et al. (2002) for the VNOS questionnaire (Interview protocol is provided in Appendix G). Each interview took about 45 minutes, and all was audio recorded for transcribing.

Exit Interview

Exit interview was accomplished at the end of the program, and it was like to sum up the whole 13-month ExpERTS program. It has 32 questions in five parts including to ask their teaching experience during the summer science camp, program components influence on their teaching, how they feel about their science identity, their NOS and SI concepts and PCK relation, and wrap up of program outcomes (the whole interview protocol is provided in Appendix H). Each exit interview took about 1.5 hours, and these all was audio recorded for further analysis.

Observations and Video Recordings

In order to understand how PCK for NOS and NOSI is developed for preservice teachers during the program, extensive observations were conducted, in addition to the collection of all related data (e.g., questionnaires, interviews, lesson plans, reflections, etc). Observations started at the beginning of the Fall semester with the monthly meetings for explicit/reflective teaching NOS and SI. It was continued on the following semesters during the NOS and NOSI course and teaching two-weeks science camp. Observations were purposefully undertaken to maximize the productive time spent by the observer in participants' teaching, and to insure the teachers had the intention of including aspects of NOS and NOSI in their instruction for the particular lesson.

All classroom observations with field notes focused on (1) data to inform the generation of a general profile for each case, (2) non-verbal data (e.g., writing on the board, student movement, and observational notes), and (3) the specific inclusion of NOS and SI. These notes provided data not readily apparent when re-watching to the related video, but also provided a means for better accessing and analyzing the video data, as the notes were synchronized with the video through the recording device.

All classroom discussions, student microteachings, demonstrations and follow-up discussions were video recorded for further analysis.

Student Works and Assignments

Lesson Plans and Teaching Reflections

As explained in the context of the study above, preservice teachers were asked to create four lesson plans for their teaching in two-weeks science camp. Each lesson plan included at least one aspect of NOS or NOSI which have to be taught explicitly and reflectively by embedding the science content. Preservice teachers started to develop the lesson plans during the NOS and NOSI course in the spring semester. The course instructors reviewed each lesson plan, and they gave informative feedback to make them ready for teaching in summer. During the two-weeks summer camp, preservice teachers used the final lesson plans in their teaching practicum (An example of lesson plan is provided in Appendix M). After each day, they were asked to write a reflection essay about their teaching. Some questions were asked them to answer on their reflection essays.

Demonstrations and Microteachings

Preservice teachers were required to do 10 minutes demonstration of an inquiry based science activity. Before each demonstration, they were asked create a lesson plan for these demonstrations. It was also the first lesson plan for them just before to create their actual lesson plans. Then, they taught one of the lesson plans in the class with their partners. Teaching took approximately 1 hour; the following discussion took about 30 minutes. Both demonstrations and microteachings were video recorded, and preservice teachers watched their own teachings for writing a reflection essay about their own teaching.

Teaching Philosophy, Science Autobiography, Why does NOS matter, and Concept Map

Additional students' works were collected including a science autobiography (each participant wrote a one page science autobiography), concept maps (participants created a concept map about their understanding of NOS and NOSI), why does NOS matter essay (participants wrote an essay about why NOS matters for teaching science), and pre-and post teaching philosophy (each participant wrote a one page essay which reflects their conception of teaching and learning, a description of how they teach, and justification for why they teach that way).

Data Analysis

All data was analyzed in three stages, which are described below in Figure 13. The first stage included the analysis of all the questionnaires, interviews, students' works and assignments, and classroom observations before the two-week teaching practicum. These data were analyzed in order to describe the development of their understanding of NOS and NOSI as well as their views and schema of their PCK for NOS and NOSI (Used to answer Research Questions 1 and 2.)

The second stage included the analysis data from the two-week teaching practicum. The data from preservice teachers' teaching videos, teaching reflections, and observations by the researcher was analyzed in order to understand what and how they taught regarding NOS and NOSI.

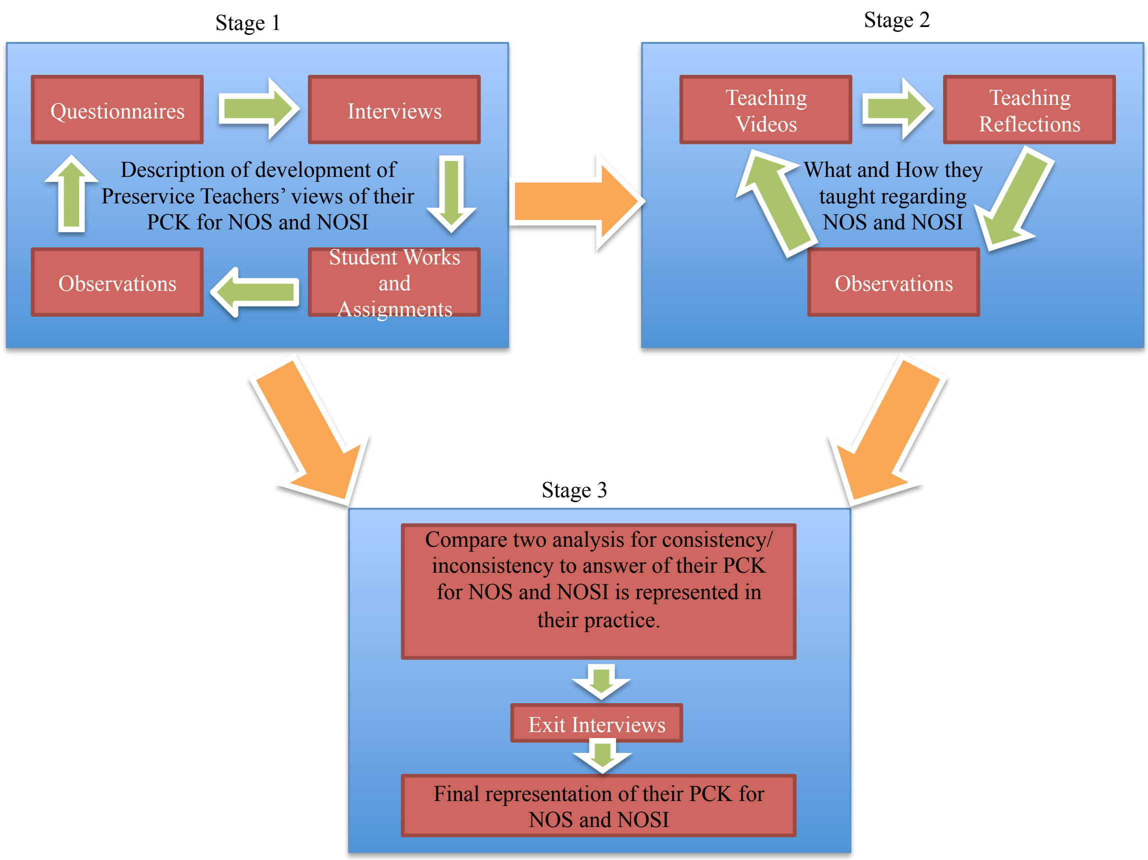

Figure 13. Stages of Data Analysis

In the last stage, the two previous analyses were compared for consistency/inconsistency to determine how their PKC was (or was not) represented in their teaching practice. Then, by analyzing exit interviews, the final representation of development of their PCK for NOS and NOSI was compiled (Used to answer Research Question 3.)

Both the VNOS and VOSI questionnaires were scored similarly. All items on each instrument are considered holistically to generate a profile of respondents' understandings across the targeted aspects of NOS and NOSI. Using the NOS views continuum, a profile for each participant was developed, describing their views on a continuum from naïve "-" to mixed "(+)" to increasing levels of informed "+, ++, +++".

The NOS views continuum enables the researcher to represent views and shifts across a spectrum (Schwartz, 2007). They were placed in the "-" range to indicate the participant's views do not agree with currently accepted views (the consensus view) of that particular aspect of NOS, the "+" range to indicate the participant's agreement that the particular aspect is representative of NOS, the "++" range to indicate the participant's abilities to articulate the meaning of the aspect in his/her own words, and the "+++" range to indicate the participant's abilities to articulate the meaning of the aspect in his/her own words and provide examples in addition to those discussed in prior class sessions (Lederman et al., 2002). If participants demonstrated inconsistent views about an aspect, they were placed in the (+) range of the continuum and considered to hold "mixed" views. The NOS views continuum was not intended to be quantitative, nor does it intend to suggest unidirectional development of NOS views. The continuum represents a range of types of views individuals within a sample display (NOS and NOSI continuum scale is represented in Appendix C). These views may shift in either direction. Use of a continuum enables identification of the "in between" to be represented as such. "In between" are those perspectives that do not totally align with "naïve" or "informed." Likewise, the continuum enables relative representation of views within the "informed" range (less informed/ more informed/ even more informed/ etc.) (Schwartz, 2007) (Illustrative examples of informed and naive views for the NOS and NOSI are provided in Appendix D)

The CoRe survey was analyzed qualitatively. Analysis of preservice teachers' respondents to survey questions and reasons for changes in their pre and post CoRe completions, and their reflections on the process were conducted through content analysis

(Miles & Huberman, 1994) based on the themes derived from their responses to the prompts from the left hand column of the CoRe (which is the analytic frame). All analysis was made based on Magnusson et al.'s PCK model. Therefore, the prompts from the CoRe offer a defined and consistent way in which to compare and contrast participants' views of their understanding and use of the CoRe. It was designed to gain access to participants' views of the development of components of their PCK over time. All translated data was entered into the HypeResearch qualitative software program. Through the use of HypeResearch, analysis of individual items of the CoRe as well as that of the self-assessments and reflections were conducted through compound and matrix analysis of the range of combination of items in order to develop a strong overview of how the participants PCK developed.

Teachers' Pedagogical Discontentment Survey was analyzed quantitatively, but the results were interpreted qualitatively. The average meaning of Preservice teachers' responds was manually computed because of the small sample size, and a general view of the participants' discontentment and efficacy towards science were interpreted by considering the each category of the surveys.

The other data including follow-up interviews, participants' lesson plans, teaching reflections, demonstrations and micro teaching videos, teaching philosophy, science autobiography, NOS matter essay, concept map, science camp teaching videos, and exit interviews were analyzed with the similar way. Figure 14 Indicates the way of analyzing these remaining data.

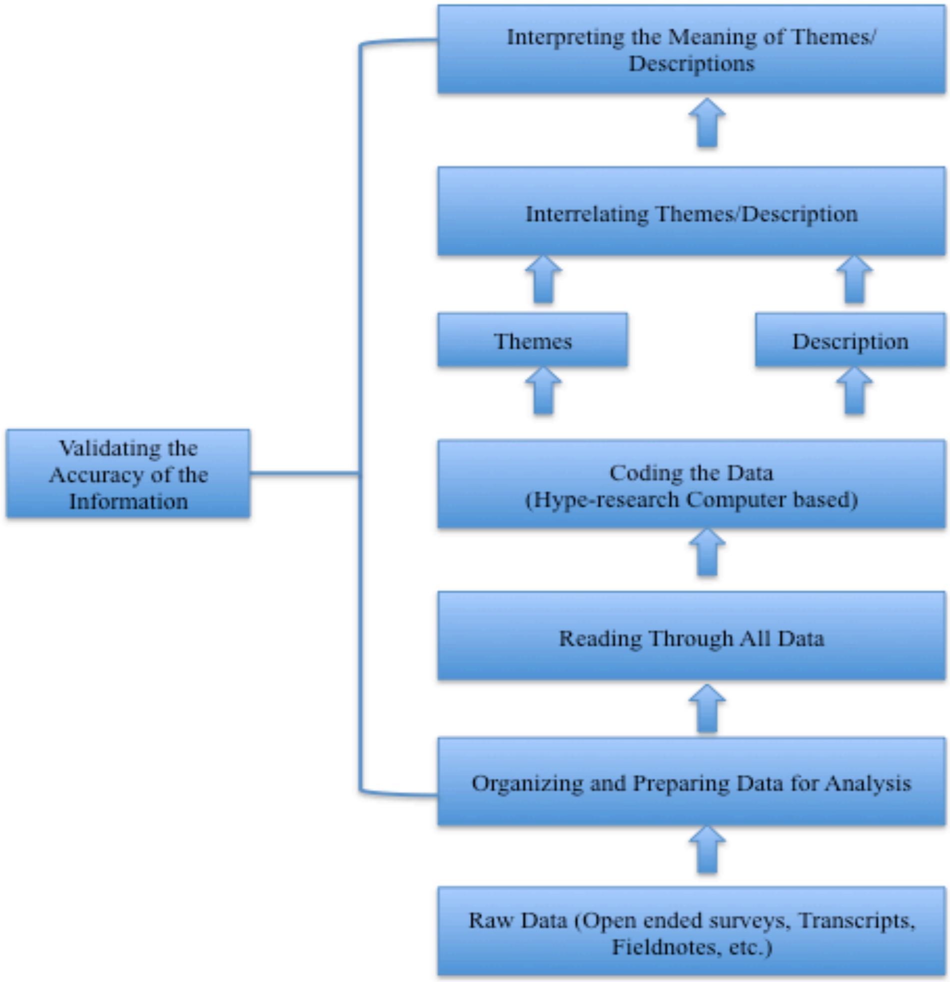

Figure 14. Analysis of Data

The analysis began with a thorough review of all data sources, assigning codes and making analytic memos to denote instances relevant to teachers' understanding of PCK for NOS and NOSI. All of this data was uploaded into the Hyperesearch software program for coding the data, category generation, and emergent themes. Themes and categories were emerged through an iterative process of engagement and reengagement with the data (Strauss & Corbin, 1998). After determining themes and categories, the meaning of themes and descriptions were interpreted.

The Researcher's Role

The role of the researcher during the 13-month program was to collect data including surveys, interviews, and observations. The researcher was the primary instrument of data collection in this study. Also, the researcher was the person who did analyze the whole data.

Trustworthiness of the Data

In order to determine the trustworthiness of a qualitative data, credibility, transferability, dependability, and confirmability are identified by Lincoln and Guba (1985). These four criteria is important for this current study 's validity and reliability in order to measure trustworthiness of the data. The validity and reliability in a quantitative study equals to these four criteria in a qualitative study mentioned above.

Credibility

The credibility reflects to "internal validity" in a qualitative study. This criteria measures how much the results of a qualitative study are confidence in the truth of the results of the study. Lincoln and Guba (1985) suggested member checks as being the most crucial technique for establishing credibility. Some interpretations of the data analysis were emailed to the participants and the participants were asked to review the interpretations of the data analysis to make sure it is reflects the views they were actually trying to convey. This study also established credibility through triangulation of the data as well as member checks. In order for validating observational data, triangulation was used as an effective technique throughout collecting and analyzing multiple data holistically, such as open-ended surveys, lesson plans, teaching videos, and interviews.

Transferability

This criterion refers to "external validity" in a quantitative study. It shows that how much the results of this study have applicability, or are transferred in other contexts. Lincoln and Guba (1985) suggested "thick description" as a technique fro establishing transferability. In this sense, since the results of this study and setting of the research were sufficiently shown with every detail, another researcher can enhance transferability throughout controlling other domains and transferring to other settings, time, and situations.

Dependability

Dependability in a qualitative study equals to "reliability" in a quantitative study. Lincoln and Guba (1985) argued that dependability refers to the consistency of the results obtained from the data based on the assumption of replicability or repeatability. The findings should make sense to someone who does not participate of this study. In order for establishing dependability, triangulation of data and an inquiry audit were used. A fair amount of data (20% of each data point) were examined and analyzed by two independent leading expert researchers who were not involved in this dissertation study. After they completed their analysis, the outside researchers and the principle researcher of this study have met couple of times until at least %90 agreements were achieved. Then, the principle researcher analyzed rest of the data based on the commonalities achieved in inquiry audit.

Confirmability

This criterion refers to neutrality or objectivity in a quantitative research. Qualitative research tends to assume that the researcher brings his/her unique perspective to the results of the study. In order to establish confirmability of the findings of this study, triangulation, and audit trail were used. Also, blind analyses were used in order to eliminate researcher bias, motivation, or interest. In addition, every detail and step of data analysis were noted by the researcher and kept in a locked drawer in order to explain the methods for developing categories, codes, and themes.

CHAPTER IV

RESULTS

In Chapter IV, case profiles are provided for each of the study participants. The purpose of the cases is to provide an in-depth profile of study participants' topic specific PCK for NOS and NOSI and their integration of the components of the Magnusson et al. (1999) PCK model. Each of the case profiles is organized in a manner reflective of the Magnusson et al. (1999) PCK model of teacher knowledge. The case profiles are presented here are based upon multiple data sources including open ended surveys, semi-structured interviews, classroom artifacts associated with the lesson, lesson plans, observations of participants teaching lessons on NOS/NOSI, and researcher field notes. The cases are based upon current conceptions of NOS/NOSI, PCK, and my interpretation of the participants' PCK for teaching lessons on NOS/NOSI.

Chapter IV provides a description of how PCK for NOS and NOSI is developed over time for each of the cases during the 13-month teacher development program. It is significantly important to represent the journey of participants' development of their PCK for NOS and NOSI during the program. This study also represents to what extent, preservice teachers translate their understanding of PCK for NOS and NOSI into the practice.

The first two sections of this Chapter provide each of the cases' NOS and NOSI understandings and their PCK for NOS/NOSI views, and changes to those views during the program. The last section reflects on the factors which mediate participants' teaching abilities and teaching practicum regarding their PCK for NOS and NOSI.

Research Question 1

How does content knowledge of NOS and NOSI change over time for preservice teachers during the ExpeRTS program?

Table 3[2]

Alignments of Participants' Views of NOS with Current Reforms

	Tentativeness			Subjectivity			Observation/Inf.			Empirical			Creativity			Theory/Law			Socio/Cultural		
	Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post
Charlie	(+)	(+)	+++	+	+	++	+	+	++	+	+	+	+	+	++	(+)	(+)	+++	(+)	(+)	+
Rose	(+)	(+)	+++	+++	+++	+++	+	+	++	+	+	+	+++	+++	+++	(+)	+++	+++	+++	+++	+++

Table 4

Alignments of Participants' Views of NOSI with Current Reforms

	Questioning			Data/Evidence			Multiple Scientific Method			Models/Modeling			Anomalous Data		
	Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post
Charlie	(+)	(+)	+++	(+)	(+)	++	+	+	+	+	++	+	++	+++	+++
Rose	(+)	(+)	+	++	++	++	+	+	+	++	++	++	++	+++	+++

[2] The meaning of the ranges was explained in data analysis section (See page 131)

Charlie's Understandings of NOS and NOSI

According to analysis of VNOS and VOSI surveys, follow up interviews, classroom artifacts, and exit interviews, Charlie started to program with mostly undeveloped and mixed views of targeted aspects of NOS and NOSI. During the program, his ideas of NOS and NOSI were highly developed, and he ended up the program with informed views of those aspects, as provided in Table 3 and Table 4. The details about his understandings of each of the NOS and NOSI aspects and the changes of those views during the program are provided below. Also, Table 5 and Table 6 are illustrated some examples from his responses. The quotes represent Charlie's views of targeted aspects of NOS and NOSI, and the changes on those views during the ExpeRTS program.

Tentativeness

Analysis shows that Charlie started the program with mixed views of tentativeness. At the beginning of the program, he believed that science has limited changing with the new information given, however he argued that scientific laws couldn't be changed at all unlike the scientific theories. According to analysis of his survey responses and follow up interview after the research section, he still held the same views (mixed) about tentativeness. He believed that scientific theories might change in the future, not scientific laws. At the end of the program, he apparently improved his understanding about tentativeness. His post concept map (See Fig.15), post surveys and exit interview clearly show that he explained this phenomenon with his own words by giving examples and found successful connection between other aspects of NOS and NOSI very well.

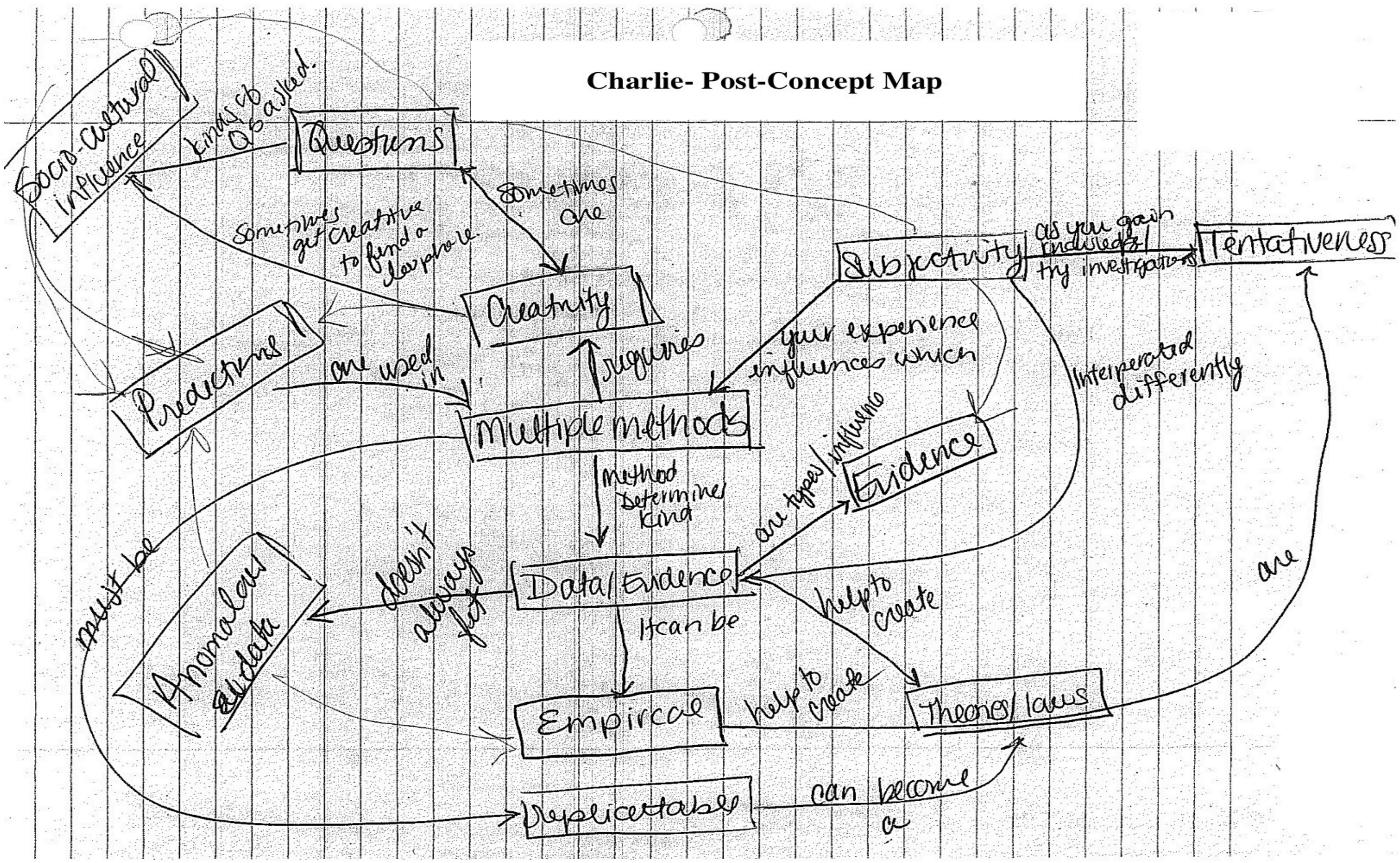

Figure 15. Charlie's Post Concept Map

Subjectivity

Analysis shows that Charlie had an informed view of subjectivity at the beginning of the program (see Table 3). He apparently explained how science is subjective. He pointed out both individual subjectivity (everybody is different and comes from different background), and theory-laden subjectivity (different fields affect scientists' investigations) in his pre-interview. Just after the research section, Charlie still had informed views. However, this level is not really enough to shift more informed (from +, to ++) view about subjectivity. He missed some opportunities to talk about subjectivity, and how it is important in science both individual and theory-laden.

At the end of the program, he improved his understanding a little bit. His post concept map (see Fig.15) shows that he made great connection between subjectivity and other aspects of NOS and NOSI, like multiple methods of science and tentativeness.

Observation/Inferences

According to analysis, Charlie started the program with mixed views of observation/inferences. He could not enough express his own knowledge about observation/inferences. He missed some opportunities that he could talk about observation and inferences. Thus, there is no best quotation, which reflects his understating about this aspect. However, he simply explained that observation is very important in a scientific research.

After research section, like his pre understanding about observation/inferences, he did talk a little bit about how observation/inference is important in a scientific investigation. It does not mean that he had an informed view about it, but we cannot definitely say that he had a naive view. In his post surveys and interview, Charlie's understand of observation/inferences was definitely developed. However, in his post concept map, he forgot to include observation/inferences on it. Again, it does not reflect his views about this aspect.

Empirical

According to all data analysis related to empirical view of NOS, there is no enough data that can be understood his view of empirical NOS. He responded very superficial to related questions in surveys and follow-up interviews. As shown in his post concept map (see Fig.15), he could not find enough connection between empirical NOS and other aspects. All those data analysis do not reflect that he had a naïve view about empirical NOS aspect. However, it does not mean that he had an informed view about it as well.

Creativity

Charlie started had an informed view about creativity/imagination at the beginning of the program. He believed that science involves creativity and ingenuity. However, he was not clear about where does creativity/imagination come play in a scientific investigation. Just after the research section, unlike to his pre responses, he talked about the parts in an investigation that creativity plays a role, but he believed that creativity is plays a role only in the beginning of the designing an investigation.

At the end of the program, Charlie's understanding of creativity was highly developed. He believed that science highly needs scientists' creativity/imagination in almost every parts of a scientific investigation. It is also important to note that he explained and find connections between creativity/imagination and other NOS and NOSI aspects (see Fig.15).

Scientific Theory/Law

At the beginning of the program, Charlie had started the program with undeveloped and mixed views about the difference and relationship between scientific theory and law. His explanations and examples of description about theories and laws were not consistent, and he seemed confused. Also, he explained that scientific laws would not change in the future because laws are laws. After the research section, Charlie's descriptions of scientific theories and laws were little bit developed, but it is not enough to shift from mix to informed.

Unlike his pre and mid views about scientific theories and laws, his post surveys and concept map showed that he believed scientific theories and laws are tentative and his connections between this aspect and other aspects of NOS and NOSI were very valuable in order to see his development during the program (see Fig.15). At the end of the program his understanding about this aspect was clearly developed.

Socio-Cultural

At the beginning of the program, Charlie had undeveloped view about socio-cultural influence of NOS. In his survey, he explained how science reflects social and cultural values. However, he argued science is also universal in his follow-up interview. He was not enough knowledge about this aspect. He was only talk about political factors can influence scientific investigation.

As far as in his pre understanding, he still held the same view that science is both universal and limited by political factors. However, he was not aware of the other potential effects of social and cultural values. He only believed that social and cultural values have negative effects on science.

According to analysis of his post data, he little bit improved his understanding about socio-cultural effect in science. He was aware of socio-cultural issues affect science as well as political influence. He also found a great connection with other aspects of NOS and NOSI (see Fig.15). However, he still talked about only negative effects of socio-cultural factors. It does not mean that he did not know about other effects of socio-cultural factors in science, but our data was not enough to say he had informed views about socio-cultural factors of science.

Questioning

Although the analysis does not give us enough knowledge about Charlie's understanding of questioning, he started the program with undeveloped view about this aspect. He missed some opportunities to talk about questions and questioning in science. However, he mentioned this aspect in his pre VNOS survey. Like his pre understanding, he did not talk enough about questioning in his mid surveys and interview.

According to our analysis, his understanding about questioning was highly developed at the end of the program. In his post survey and interview responses showed that he was completely aware of how questions are important in science. He argued science always starts and develops with questions. His post concept map also showed that he found great connection between questioning and other aspects of NOS/NOSI (see Fig.15).

Data/Evidence

According to analysis, Charlie had mixed views about data and evidence in science. He partly explained the definition of those concepts. However, his explanations were not consistent with the current views of data and evidence. He only believed that data is the numbers, and acquired through an experiment. On the other hand, evidence are based on observations and not represented by the numbers.

He improved his understanding of data and evidence after the research section of the program. His definition about data and evidence were more consistent with accepted definitions. However, he still believed that data has to be quantitative.

In his post concept map (see Fig.15), he found a great connection with other aspects of NOS and NOSI. Also, his responses on post surveys and interview showed that he explained the difference and the relationship of data and evidence.

Multiple Scientific Methods

According to analysis, Charlie started the program with an informed view about multiple scientific methods. He believed that scientists do not have to follow the same steps, and there are multiple ways to do science. However, and interestingly, he still used the term of scientific method.

After the research section, like in his pre understanding about multiple scientific methods, Charlie believed that there are multiple ways to do science, but there is a scientific method. It does not mean that he had a naïve view about this aspect, but he thought scientific methods is the acceptable way to do science, but scientists do not have to follow it.

At the end of the program, Charlie still thought that there are multiple methods to do science, and he argued scientists do not have to follow those steps. However, he still believed that there is a scientific method, and if you do not follow it, it is not called experiment, it might be called an investigation. Also, his explanations and connections on his post concept map showed he ended the program with an informed view.

Models/Modeling

According to analysis, Charlie started to the program with an informed view about models and modeling in science. He partly described what is a scientific model, and gave an example. After the research section, Charlie talked about models and modeling in science much more than his pre responses. He clearly improved his understanding about this aspect.

In his post surveys, interview, and concept map, Charlie did not talk about models and modeling. He just simply defined it and gave an example. He could include this aspect in his concept map, but he did not do it. Thus, it cannot be said that he improved his understanding of models and modeling in science.

Anomalies Data

At the beginning of the program, Charlie had an informed view about anomalies data in science. He clearly explained what and how important it is in a scientific investigation. He also talked about how scientists and students handle anomalies data in science. After the research section, Charlie held a more informed view about anomalous data in science. He explained it and gave great example from his own experiences.

At the end of the program, Charlie clearly had more informed views about anomalous data in science. His post concept map (see Fig.15) showed how he perfectly found connections between anomalous data in science and other aspects of NOS and NOSI. He defined and explained how important it is in science. Also, he explained that students and scientists handle anomalous differently.

Table 5

Representative Quotes of Charlie's Views of the Target NOS Aspects

NOS Aspects	Undeveloped Views	Informed Views
Tentativeness	"Scientific theories we have today will change in the future. Scientific laws we have today will not change in the future. Gravity will always be gravity. The fundamental properties of this law will never change." (VNOS Pre)	"Nothing in science can be proven. Everything is capable of change." (VNOS Post) "Laws have less chance of changing, but there is a possibility. We don't know what's going to happen 100 years from now." (Exit Interview)
Subjectivity	"Every scientist handles the anomalous data in science in a similar way." (VOSI Pre)	"Science and art are similar as both require you to be creative and both are subjective to the individual. Science is subjective. Each scientist holds the same information, but with differing backgrounds they can interoperate that information differently." (VNOS Post)

Table 5- Continued

NOS Aspects	Undeveloped Views	Informed Views
Observation/ Inference	"Just through observation of the fossil record, you can see how their hooves changes; you can see how they're teeth changed." (VOSI Pre)	"Science is not just experimentation, but also observation. You can study fossil record doing observation and inference. You can be like, "Okay. Well, these bones fit together this way. These ones are more complex. Or, These ones are less complex. There's a process to it, using observation and inference." (Exit Interview)
Empirical	There is no data to show his "undeveloped" view of Empirical.	"Scientists use fossil records to reconstruct the build of a dinosaur and then apply the natural laws and extrapolate the information giving their best hypothesis on how dinosaurs looked and functioned. "(VNOS Pre) "Science is based on empirical evidence and observations, which includes scientists' subjectivity. (Exit interview)

Table 5- Continued

NOS Aspects	Undeveloped views	Informed Views
Creativity	"Scientists only use creativity in the planning part." (VNOS Pre)	"Scientists use their creativity in every part of an investigation. Especially in planning. They also have to do it in the conclusions. Creativity can come into that when deciding and interpretation. (Exit Interview)
Theory/law	"A scientific theory is the explanation of why something is happening. A scientific law is the description of an observation." (VNOS Pre)	"A scientific theory is an explanation of how something works. A scientific law is an description of what is happening." (VNOS Post)
Socio/Cultural	"Science is universal. Like, I could go to Germany or a different country, and I could speak science, and they would understand what I'm talking about as long as they speak science." (Interview Pre)	"Science does reflect political and social values. Scientists are limited to the research that is deemed moral and acceptable in today's society. Live human testing is not tolerated in some nations. Therefore science is affected." (VNOS Post)

Table 6

Representative Quotes of Charlie's Views of the Target NOSI Aspects

NOSI Aspects	Undeveloped Views	Informed Views
Questioning	"Science and art are different as to the approach. Science is usually begun, in my experience, with a question. How does this work? Why? What does it do?" (VNOS Pre)	"Without question there is neither advancement nor an increase in understanding. Everything is changing and without questions we become stagnant." (VOSI Post) "Science all starts with the questioning."(Exit Interview)
Data/Evidence	Data is the information acquired through an experiment. It is quantitative. Data and Evidence are different because evidence can be qualitative and quantitative." (Interview Pre)	Data is the raw information collected through observation or experimentation. Data and evidence are different; evidence is your interpretation of the data. (VOSI Post)

Table 6- Continued

NOSI Aspects	Undeveloped Views	Informed Views
Multiple Scientific Methods	‘Experiment is a set protocol where you have variables and constants. The variable is tested and measured against controls. There is usually a hypothesis and an expected outcome. Data is used to support or not support the hypothesis. Scientific Method.” (VOSI Mid)	“Not all “scientific methods” need to follow exact steps. Sometimes there is no way to design an experiment that involves variables or a hypothesis.Observation is a perfectly acceptable way to “do science” and it follows none of the steps involved.” (VOSI- Pre)
Models/Modeling	There is no data to show his “undeveloped” view of Models and Modeling.	“A scientific model is a representation of a system that is otherwise unable to be seen or is difficult to envision. Cell Model.” (VNOS Post)
Anomalous Data	“Data that is collected that does not fit with the rest of the data. These outliers are usually discarded and though of as accidents.” (VOSI Pre)	“Anomalies are found when analyzing your data. They will fall outside of the normal, or through observation. They will not follow the normal pattern.” (VOSI Post)

Rose's Understandings of NOS and NOSI

According to analysis of VNOS and VOSI surveys, follow up interviews, classroom artifacts, and exit interviews, Rose started the program with "informed" and "mixed" views of targeted aspects of NOS and NOSI. During the program, her understandings of the most of those aspects of NOS and NOSI were highly developed, and she ended up the program with very informed views of those aspects, as provided in Table 3 and Table 4. The details about her understandings of each of the NOS and NOSI aspects and the changes of those views during the program are provided on the below. Also, Table 7 and Table 8 are illustrated some examples from her responses. The quotes represent Rose's views of targeted aspects of NOS and NOSI, and the changes on those views during the ExpeRTS program.

Tentativeness

According to analysis, Rose had mixed views about tentativeness at the beginning of the program. She explained scientific theories are always changing with new information and technologies, even in the unrelated questions. However, she believed that scientific laws would not change in the future. By the middle of the program Rose held mixed views about tentativeness as well. She explained that science is tentative, even theories or laws can change with new information. However, in her mid interview, she confused about changes of law of gravity, and her mid-concept map (see Fig.17) showed that she still believe that there are facts in science that influence theories and laws.

According to analysis of Rose's post data, She clearly and simply explained that science is tentative and always changing, even theories and laws that we have today. Her post concept map (see Fig.18) showed that she found great connections with other aspect of NOS/NOSI.

Subjectivity

Rose started the program with an informed view about subjectivity. She clearly described science is subjective. All scientists have different background, and different fields of work, which influence their studies. She was also aware of individual and theory-laden subjectivity. Also, she included this aspect on her pre concept map (see Fig.16). During the course, Rose's idea of subjectivity was developed, and she ended up the program with informed views. Also her post concept map (see Fig.18) showed that she found a great connection between subjectivity and other aspects of NOS and NOSI.

Observation/Inferences

At the beginning of the program, Rose pointed out how observation is important in a scientific investigation. However, she never talked about how inference is related to observation. She only emphasized inferences in her pre concept map (See Fig.16). It does not mean that she had a naïve or mixed view about this aspect.

On the middle of program, unlike her responses of pre surveys and interview, Rose did not talk about observation and inferences enough.

At the end of the program, she ended up with more informed views about observation and inferences. In her post concept map (see Fig. 18) showed that Rose also found clear connection between observation/inference and other aspects of NOS and NOSI. Although there was not a direct question about the definitions and the difference between observation and inference, she tried to emphasize on observation and inferences in many different questions.

Rose Pre-Concept Map

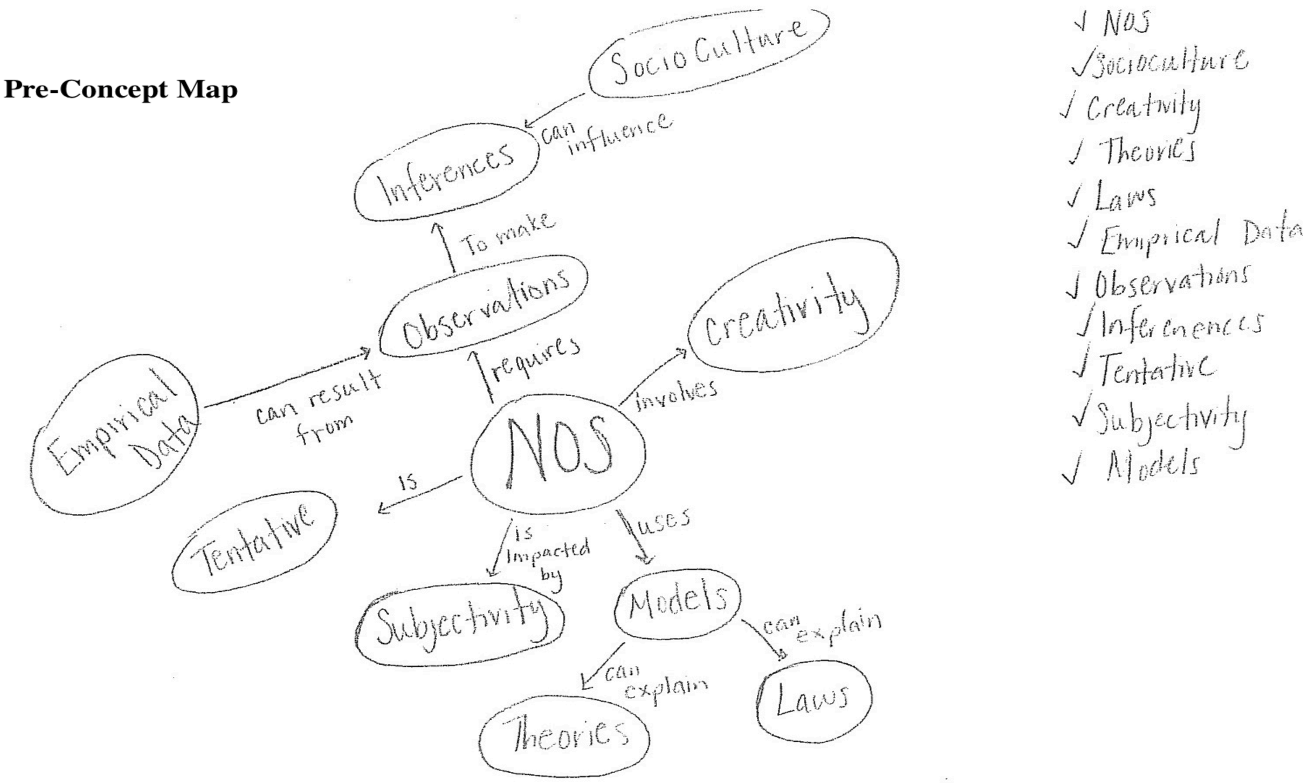

Figure 16. Rose's Pre Concept Map

Rose Mid-Concept Map

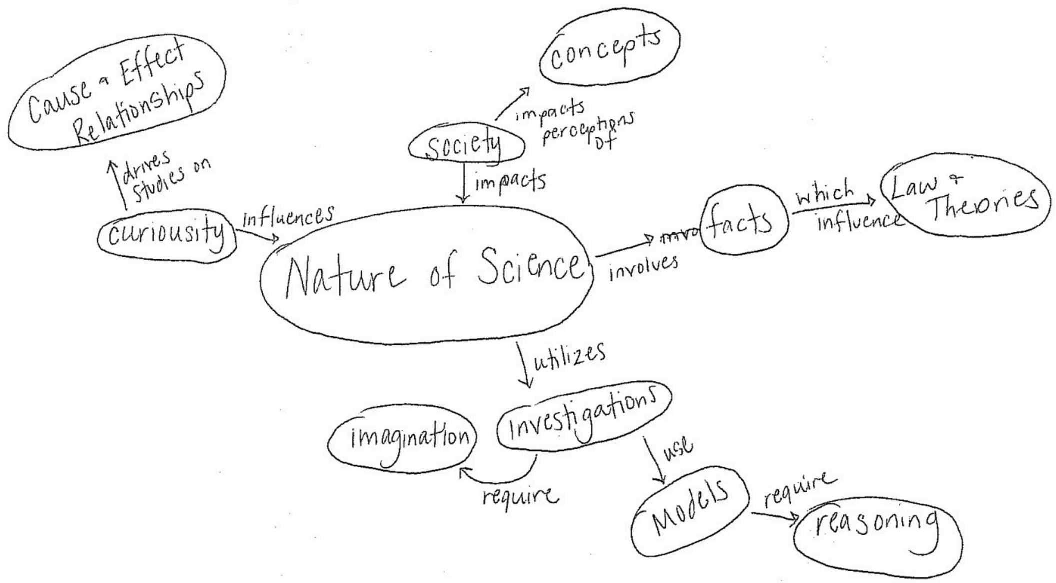

Figure 17. Rose's Mid Concept Map

Rose Post-Concept Map

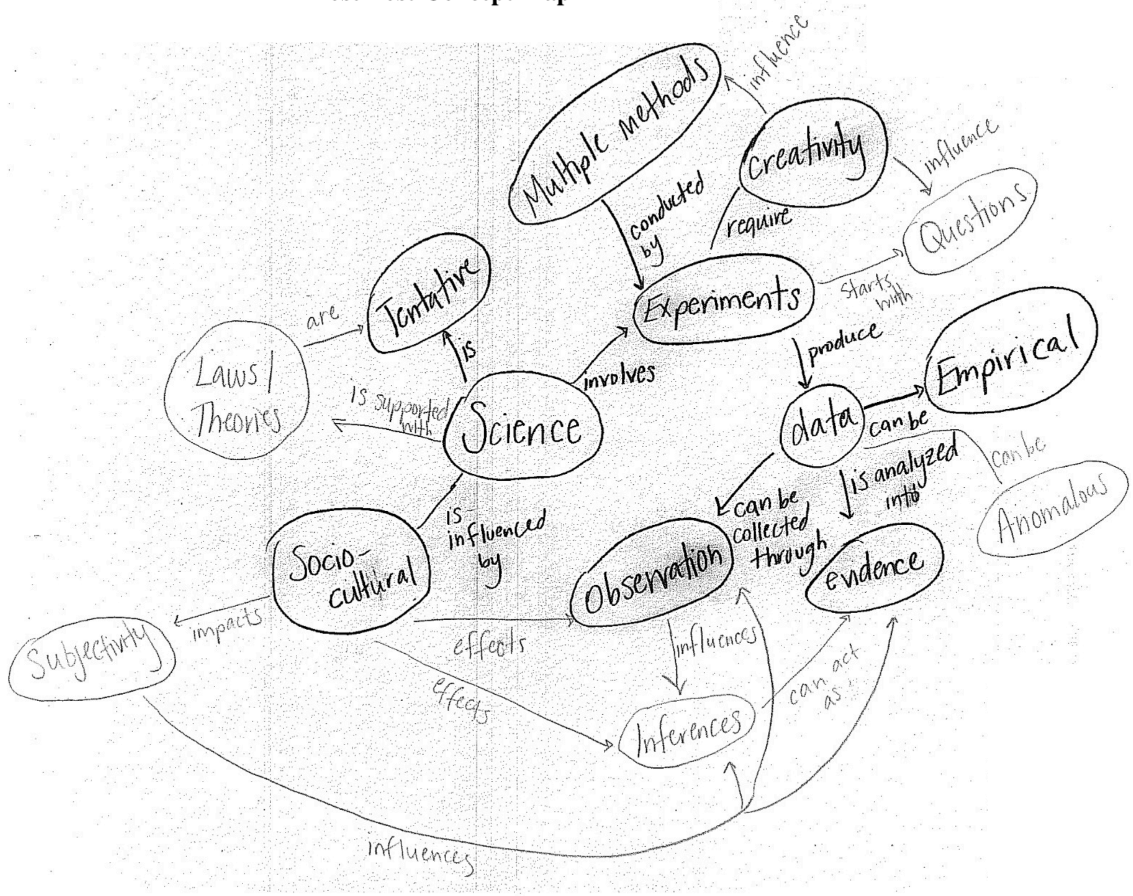

Figure 18. Rose's Post Concept Map

Empirical

At the beginning of the program, Rose had an informed understanding about empirical view of science. She believed that science is based on empirical data, which influences from observations/inferences and scientists' subjectivity. Also she emphasized this aspect on her pre concept map (see Fig.16).

In her mid and post views about Empirical NOS, there was not enough data to understand changes on her views during the program. However, it can be definitely said that she had informed views about empirical NOS. She also pointed out empirical NOS in her post concept map as well (see Fig.18).

Creativity

At the beginning of the program, Rose had very informed views about creativity. She explained very well how creativity plays a role in a scientific investigation. She believed that each part of an investigation needs a certain amount of creativity (see Fig.16). Also, she pointed out the importance of creativity with giving an example from her experience.

By the middle of the program, unlike to her pre understanding about creativity, Rose interestingly argued that the interpretation part of an investigation do not need creativity because it has to be supported by the data. However, She still had an informed view about this aspect. Also Rose highly expressed that students need to understand science involves creativity and critical thinking. That is very important to understand how she was aware of the importance of this aspect. Also, she highly emphasized this aspect on her mid concept map (see Fig.17)

Analysis showed that she ended up the program with very informed views about creativity in science. She simply explained how creativity is important and it is necessarily needed in every part of a scientific investigation. Her post concept map also showed that how she find connection between creativity and other aspect of NOS (see Fig.18).

Scientific Theory/Law

Unlike the other aspects of NOS, Rose started the program with undeveloped views of the relationship and difference between scientific theories and laws. In the survey and follow-up interview, she was confused about this aspect of NOS. Her beliefs were also very inconsistent both within and between the surveys and interview. Also, her pre concept map showed her mix view about this aspect (see Fig.16).

After the research section, Rose dramatically improved her understanding about scientific theories and laws. She simply explained the definitions of those concepts and how those re related to each other (see Fig.17). She also believed that scientific theories and laws might change with new information and technologies. At the end of the program, Rose ended with informed views about scientific theories and laws. Also, in her post concept map, she simply explained the connections with other aspects of NOS and NOSI (see Fig.18).

Socio-Cultural

At the beginning of the program, Rose started the program with an informed view about socio-cultural effect of science. She explained how socio-cultural values affect scientific investigations even in the unrelated questions to this aspect. Also, she illustrated her understanding on her pre concept map (see fig.16).

Like in her pre and mid views, Rose ended up the program with more informed views about socio-cultural value. In her post concept map, she found great connection between this aspect and other aspects of NOS and NOSI (see Fig.18).

Questioning

There was no enough data to understand Rose's view about questioning at the beginning of the program. She also did not point out this aspect in her pre and mid concept map.

At the end of the program, she used questioning and its connection with other aspects in her post concept map (see fig.18). Also, in her exit interview, she expressed that science always starts with a question.

Data/Evidence

At the beginning of the data, Rose had informed view about data and evidence. She clearly defined data and evidence, and explained the difference between them. After the research section, she extended her explanations, and believed that data can be numerical or a description.

At the end of the program, Rose had very informed views about data and evidence, She also found great connection between data/evidence and other aspects of NOS and NOSI (see Fig.18).

Multiple Scientific Methods

At the beginning of the program, Rose taught that there is no only one way to do science. There are multiple ways to do science. However, she believed that if there is an experiment, scientists have to use scientific method. Thus, it might be said her view of this aspect is undeveloped.

After the research section, she recognized that there are multiple ways to do science. Scientists do not have to follow exact same orders. However, she sometimes used the term of “scientific method”.

At the end of the program, she was aware of there are multiple methods in science, and it can be used in a various forms. However, she still thought “scientific method”, that is frequently known, is a good way to do science. Thus she ended up the program as she started, which is between the undeveloped and informed view. Also, she used this aspect on her post concept map (see Fig.18).

Models/Modeling

At the begging of the program, Rose had very informed views about models and modeling in science. She was aware of how models are used in science, and how important it is. Also, her pre concept map showed that she thought models are used in science, and those explain scientific theories and laws (see Fig 16).

After the research section, she had very informed views about this aspect. She recognized that model is a replication of something that cannot be directly handled or observation for scientific study. Also, she used this aspect on her mid concept map (see Fig.17). At the end of the program, Rose ended up the program with informed views about models and modeling as well.

Anomalies Data

Related to anomalies data in science, Rose started the program with an informed view about this aspect. She defined anomalies in science, and explained how important it is. Also, she compared how students and scientists handle anomalies in science.

After the research section, Rose explained how scientists and students could use anomalies in science. She also gave example from his research experiences. She recognized that all scientist explore anomalies and determine how or why they occurred and what that means for their experiment overall.

At the end of the program, Rose ended up with very informed views about anomalous in science. Her post concept map showed that data can be anomalous, but she did not find connection between this aspects and other aspects of NOS and NOSI (see Fig.18).

Table 7

Representative Quotes of Rose's Views of the Target NOS Aspects

NOS Aspects	Undeveloped Views	Informed Views
Tentativeness	"Scientific laws do not change, the law of gravity will always remain true." (VNOS Pre)	"Science and technology is always changing and evolving, therefore theories and laws will change in the future. Everything is always changing." (VNOS Post)
Subjectivity	There was no data to show her undeveloped view of subjectivity.	"All scientist coming from different society and cultures, this causes them to have different views on science. Different scientist has different views. Science is subjective" (VOSI Pre)

Table 7- Continued

NOS Aspects	Undeveloped Views	Informed Views
Observation/ Inference	"I view science as something that can be observed, measured, etc. To determine if something is science or not, it needs to be backed with evidence, facts, data and observation."(VNOS Pre)	"By teaching NOS, students need to understand the difference between observation and inferences." (Why does NOS matter essay) "Scientists do all sorts of things to learn about the natural world. They make observations, inferences, and conduct experiments." (VOSI Post)
Empirical	There is no data to show her "undeveloped" view of Empirical.	"I view science as something that can be observed, measured, etc. To determine if something is science or not, it needs to be backed with evidence, facts, data and observation." (VNOS Pre) "Scientists use the fossils they discover to make models of dinosaurs and observe how the bones work and move together. (VNOS Mid)

Table 7- Continued

NOS Aspects	Undeveloped views	Informed Views
Creativity	"The majority of creativity takes place during the development of the experiment.However the interpretation still needs to be backed by the data, so there is not as much room for creativity." (VNOS Mid)	"Students need to understand that science is tentative and requires creativity and critical thinking." (Why does NOS matter) "Scientists use their own creativity in every part of an investigation" (Exit Interview)
Theory/law	A scientific theory explains how something happened, and then the scientific law explains why it happens." (Interview Pre)	A scientific theory explains a phenomenon or law. Theories are explanations. A scientific law just states the phenomenon.(VNOS Post)
Socio/Cultural	There is no data to show her "undeveloped" view of Socio Cultural Value.	"Every scientist comes from different socio cultural background and different kinds of prior knowledge; therefore they will all apply their thinking differently to understand the same amount of information." (VNOS Post)

Table 8

Representative Quotes of Rose's Views of the Target NOSI Aspects

NOSI Aspects	Undeveloped Views	Informed Views
Questioning	There is no data to show her "undeveloped" view of Questioning.	"I always encourage my students to ask more questions because that's where science starts. You start with a question, with a curiosity." (Exit Interview)
Data/Evidence	There is no data to show her "undeveloped" view of Data Evidence.	"Data is any information collected by observing or testing something. It can be numerical, or a description of what is being studied." (VOSI Mid) " Data and Evidence are different. Data is collected, and then analyzed. Once analyzed, the information is then used as evidence to support whatever conclusion can be drawn from the experiment." (VOSI Mid

Table 8- Continued

NOSI Aspects	Undeveloped Views	Informed Views
Multiple Scientific Methods	"There are many ways a scientist can conduct an experiment or investigation, but regardless of how they do it, it has to be able to be replicated by any other scientist. I think that's still a method being used." (VOSI Pre)	"I think there are important aspects that are involved in a scientific method, but these aspects can be used in various forms and at various steps within an experiment. As long as the experiment can be understood and replicated by another scientist then it is a good method." (VOSI Post)
Models/Modeling	"Scientist use models and observation to replicate things that they are not able to see directly." (VNOS Pre).	To understand various phenomenon, scientists observe and infer various forms of information and then make models to test the information they've gathered to make sure their model acts the same as the phenomena they trying to replicate." (VNOS Post)
Anomalous Data	There is no data to show her "undeveloped" view of anomalous data.	"An anomaly is a piece of data that is inconsistent with the rest of data by a large amount." (VOSI Post)

Research Question 2

Descriptively, what was the Pedagogical Content Knowledge of two preservice teachers during a teacher development program.

Charlie's PCK for NOS/NOSI

In this section, pre/post CoRe, pre/post Pedagogical discontentment surveys, follow up interviews, classroom artifacts, teaching philosophy, and exit interviews were analyzed to understand how pedagogical content knowledge for NOS/NOSI changed for Charlie during the teacher development program.

Primary data sources for understanding participants' PCK for NOS/NOSI are pre and post CoRe and follow-up interviews. As explained in Chapter III, at the beginning of the second section of the whole program, each participant selected three big ideas from the targeted list of NOS or NOSI aspects in order to fill out the CoRe survey. Charlie's big ideas were tentativeness, subjectivity, and multiple scientific methods. At the end of the second section, each participant selected 5 big ideas (the first three ideas had to be the same as in pre-CoRe) from the targeted list of NOS or NOSI aspects. He added two more big ideas, which were questioning and scientific models on his post CoRe. During the second section (NOS and NOSI course), classroom artifacts including demonstration lesson plans, teaching reflections, classroom videos, and researcher's field notes were analyzed for understanding the changes of his PCK for NOS/NOSI during the program. Also, his pre and post pedagogical discontentment survey were analyzed to find out his discomfort level with regard to pedagogical content knowledge.

Orientation Towards Teaching Science

According to analysis of his pre CoRe survey responses and follow up interview, Charlie mostly holds “didactic” and “activity driven” orientations towards teaching science in general and specifically for NOS/NOSI. However, it does not mean that he has enough knowledge about orientations towards teaching science for NOS and NOSI. For example, his CoRe survey responses of first big idea about tentativeness showed he would use “didactic” orientation towards teaching tentativeness. Here are some examples from his pre CoRe survey and follow up interview:

> Question: What teaching procedures will you use and what are the particular reasons for using these to engage with this idea (Tentativeness)?
>
> Charlie: “I would use compare and contrast…what did you know when you began this course, how do you better understand it now. What did the population use to believe about how world functions vs now? Examples of progression. World is flat? Everything is made of the four/five elements/solar system.” (CoRe Pre)
>
> Question: So, could you please be little bit more specific on the teaching procedures you are going to teach tentativeness. I mean, in your survey, you responded mostly general teaching strategies in science, but how can you exactly give specific example for teaching tentativeness?
>
> Charlie: “So, kind of like — so, I guess when I was talking about this, like compare and contrast, I would have them answer a question about something. And then, we’d learn about it. And then, we’d go back to their question. And how did their answer change? And so, that would be an

example of tentative, because this is how they thought it worked, but they were presented more information, and this is how they think it works now. And then, I could use how has in like the real world, how has tentativeness affect science and the way we think? And you can relate that back to how the world was flat and it's really round or how we thought the solar system revolved around Earth, but really it doesn't." (CoRe Follow-up Interview Pre)

Related to his second big idea "subjectivity," Charlie thought that he could teach it by using "activity driven" and "guided inquiry" orientations towards teaching. Some illustrative quotations show his pre knowledge about orientation teaching science for subjectivity.

Question: What teaching procedures will you use and what are the particular reasons for using these to engage with this idea?

Charlie: "Use of experimentation to determine an answer to a question. Show how each group came up with different solutions and it's possible all are correct even though they are different – rope and tube model[3] as well."(CoRe Survey pre)

Question: What is the best way to teaching subjectivity?

Charlie: "Well, you do an experiment, and let the student come up with their own answers. And then, you could just let them share what their answers are, and I doubt everybody would have the same answer. And

[3] This activity was explained in the Chapter III as an example of explicit/reflectivity NOS/NOSI activity.

then, you could point out they're not all wrong. Like each of them has a valid point. Like the storeroom (ph) used when they were doing the dyes, and then, they were like, "Well, why does it sink? Why does this one float?" Like everybody had different answers. And so, I feel like it's a very efficient and easy way to drive the point."(CoRe Follow-up Interview Pre)

Related to his third big idea "Multiple Scientific Methods," he believed that it would be taught best by using an "activity driven" orientation. Some examples from his survey and interview show his knowledge about it:

Question: What teaching procedures will you use and what are the particular reasons for using these to engage with this idea?

Charlie: I would use a procedure that uses observation and no experimentation and will have them define what science is to them and see if the observations technique fits within their definition. I will use the examples like Darwin, or the fossil record. (CoRe Survey Pre)

Question: What about the teaching procedures? What is the best way of teaching multiple scientific methods?

Charlie: So, I would have a lesson or an investigation that I don't want to say couldn't, but it would be very hard to fit within the classical scientific method. Because I feel like if by doing that, it would kind of force them to think outside of. And then, it would be their own realization that, "Hey, this, like — because I would — they would think that they're doing science. Like they would be doing science. And then, I would like them to

> have them draw on — like make the connection themselves rather — and that's better than just me saying — just observing something is science as well. And so, do something like — I don't know. I use the example like Darwin and like the finches, and their beaks, and stuff like that. And so, like I (ph) could observe different pictures of different animals and be like, "Well, why are they different?" Like they could be similar, but like you can chipmunk or a squirrel, or like the different kind of like fish, or just stuff like that. (CoRe Follow-up Interview Pre)

In conclusion, at the beginning of the program, Charlie tried to answer those related questions both in CoRe survey and follow-up interview, but he did not give us enough information about his own knowledge of orientation towards teaching NOS/NOSI aspects. The only thing that he specifically wanted to use was an "activity driven" orientation to teaching NOS/NOSI aspects for eighth graders as a targeted group of students.

> Question: How would you maximize student learning in your classroom?
>
> Charlie: From my experience as a student, and what I expect from a professor, I don't think learning or teaching should be one way. I don't learn well from just a lecture, so I'm not going to teach with just a lecture. I will have models and I will have activities. I actually really enjoy it when they give me a piece of paper that's, "This is DNA and this is how it separates. Put your pieces where they're supposed to go," or if I'm supposed to build the D - it helps me to understand it if I can visualize it, and if I'm working with it and making my mistakes, and then having my

> mistakes fixed. And so like as a professor or a teacher, I want to maximize all the different tools that I can use - like I'll use PowerPoint or some hands-on...maybe we'll do a trip out to the nature preserve and work with trees - I don't know depending on what I'm teaching or whatever. But I don't want to be relying strictly on lecture, and I don't want it to be boring. If it's boring, and then you don't...you lose the interest of your class. Like I want... I find it exciting, and I want them to find it exciting, so I'm going to try to make it exciting for them. (NOS/NOSI Interview Pre)

During the course, Charlie designed his demonstration lesson plan based on activity driven orientation towards teaching "chemical and physical change/reactions" (Charlie's demonstration lesson plan is provided in Appendix L).

In his one-hour microteaching, as explained in Chapter III, Charlie and Rose were partners, and they mostly used didactic teaching. They presented information, generally throughout lecture or discussion, and questions directed to students.

At the end of the course, Charlie mostly held ideas to use "activity driven," "discovery," and "inquiry" based teaching. He would like students to participate in hands-on activities used for verification or discovery. Also, he wanted to organize his lesson based on student centered, which led students to explore the natural world following their own interest and discover patterns. In addition, his data showed that Charlie would like to plan based on investigation centered teaching, which helps teachers to support students in defining and investigating problems, drawing conclusions, and assessing the validity of knowledge from their conclusion. Here are some examples from his post CoRe and follow-up interview.

Related to his first big idea "Tentativeness," he changed his teaching procedure from "didactic" to "Activity Driven" and "Discovery."

> Question: What teaching procedures will you use and what are the particular reasons for using these to engage with this idea?
>
> Charlie: "I would like to use an investigative approach where students solve a problem. After they solve the problem I would then provide them with new information and see how that affects their solutions and ideas." (CoRe post)
>
> Question: For the procedures or strategies, why did you choose this strategy to teach Tentativeness?
>
> Charlie: "I feel like it's the easiest way to show tentativeness, because if you're doing an investigation, you're the one, you're doing everything. You're designing it. This is like your raw data, so you'll do it. If you don't get something, how you expect it to be, maybe you look at it. You have to change your parameters, like that's still tentativeness to me, because you're getting back information; oh, that's not what I expected. Well, maybe if I change it like this, it will be more applicable to what I'm looking at, and then you get the information." (CoRe Follow-Interview Post)

Related to his second big idea "Subjectivity", Charlie wanted to teach subjectivity through "Activity Driven" and "Inquiry" approaches.

Question: What teaching procedures will you use and what are the particular reasons for using these to engage with this idea?

Charlie: "I will use inquiry based investigation to demonstrate the subjective nature of science. There will be class discussion to share ideas and discuss how each solution works…some may be better than others though." (CoRe Post)

Question: What kind of teaching procedures you are going to choose to teach subjectivity and why?

Charlie: "I guess, I don't know, kind of the same as like tentativeness, like an investigative process. When we do our - like when we're going to do our group work this summer or whatever, they're set up in different groups, and so I'm expecting that one group won't have the same answers as the other group, and then I would just point that out where I'd be like, well why do you think their answers are different? Do you think that makes their answers wrong? That's how it would go about." (CoRe Follow-up Interview Post)

Unlike the other big ideas, related to his third big idea "Multiple Scientific Methods," Charlie wanted to teach this subject via the teaching orientation of "process" and "Inquiry." He first wanted to introduce students to the thinking processes employed by scientists to acquire new knowledge. Students engage in activities to develop thinking process and integrated thinking skills.

Question: What teaching procedures will you use and what are the particular reasons for using these to engage with this idea?

Charlie: “I will use an investigative process that requires only observation and inference to solve/answer a question. I will then relate this to inquiry based investigation and scientific method experimentation.” (CoRe Post)

Related to his fourth and fifth big ideas, “Questioning,” and “Scientific Models,” Charlie choose “activity driven” to teach those aspects of NOSI.

Questions: What teaching procedures will you use and what are the particular reasons for using these to engage with this idea?

Charlie: “They need to formulate all aspects of the investigation from start to finish helping them understand that without the first question or goal there can’t really be anything after.” (CoRe Post)

Question: What other factors influence your teaching of this idea?

Charlie: “I am a hands on learner so I like to use models as a tool when describing advanced concepts and ideas.” (CoRe Post)

In conclusion, Charlie started to try alternative and different teaching orientations to teach NOS and NOSI aspects. He was mostly aware of the importance of inquiry based learning and changing students’ understanding conceptually. He specifically chose the teaching orientations, “Activity driven” and “Inquiry.” His pre and post pedagogical discontentment survey showed he believed that using inquiry based teaching within all content areas is very important to teach science, and he did not have any discontentment to teach science via inquiry.

Knowledge of Science Curriculum

This refers to Charlie’s knowledge about science curriculum materials available for teaching a particular subject matter as well as about both the horizontal and vertical curricula for a subject. Magnusson identified two types of curriculum, knowledge of goals and objectives, and knowledge of specific curricular program (materials that are relevant to teaching a particular domain of science). However, it is very hard to understand his knowledge of science curriculum without analyzing his lesson plans and actual teaching practices. His pre and post pedagogical discontentment survey responses showed to what extent Charlie feels discontentment while teaching a science subject. Also, during the CoRe and follow-up interviews, "what do you intend the students to learn from this idea?" and "why this idea is important for students to know this?" questions were used to understand his knowledge about science curriculum.

For example, related his second big idea "Subjectivity," Charlie explained why subjectivity is important for students to know. It is very important to know to what extent he knows the objectives and standards about subjectivity.

> Question: What do you intend the students to learn about this idea?
>
> Charlie: "I want them to be able to understand that each person brings their own unique view point and that not everyone comes to the same conclusions when given identical data/information." (CoRe Pre)
>
> Question: Why it is important for students to know this?
>
> Charlie: "They need to know that just because someone disagrees with them it doesn't make them wrong, and it doesn't mean that they are right either. There are multiple ways to interoperate results and it is how you argue your case and shape the results toward your argument that is crucial." (CoRe Pre)

Related to his third big idea “Multiple Scientific Methods,” his content knowledge and knowing why he wanted to teach this idea are very important to realize his knowledge about science curriculum.

> Question: What do you intend the students to learn about this idea?
>
> Charlie: “There is no correct way when doing science.”
>
> Question: Why it is important for students to know this?
>
> Charlie: So that students don’t get caught up trying to figure out how to do science within the constraints of the classical scientific method.”
>
> Question: What else do you know about this idea (that you do not intend students to know yet)?
>
> Charlie: “It is not all experimentation but also observation, speculation, and ingenuity.”
>
> Question: What difficulties/limitations are connected with teaching this idea?
>
> Charlie: “I would assume that they have been taught the classical method of the scientific method and they will want to hold to that idea.” (CoRe Pre)

His pre Pedagogical Discontentment Survey also showed that he did not have any discontentment about science curriculum. This element was one of the highest levels in his pre discontentment survey. Here are some example statements, which indicate his level of discontentment in terms of his own science teaching. (as explained in Chapter III, level 1 indicates “no discontentment”)

“Balancing personal science teaching goals with those of state and national standards.” (Level: 1)

“Finding connection between science content and students’ everyday lives.” (Level 1)

“Integrating NOS, throughout the curriculum.” (Level: 2)

Also in Charlie’s pre interview, he gave some ideas about his knowledge of science curriculum.

Question: How do you know when to move on from a different topic?

Charlie: “Well, when you’re teaching with a large classroom, you need to be very understanding, or...it always needs to be at the front of your mind that there’s different learning levels. There’s going to be a trend, some people are going to pick it up right away; some are not. And I don’t think it would be fair as a whole to stay on a topic until it’s layers are like - because it’s not fair to the other students. Um, I guess it would be a touch and go kind of thing. I don’t think there is a set way. It’s just because you have homework and you have tests and you have quizzes. I guess if everyone is doing really well in their work, and then you could be like, “Ok, I think this is fairly well understood.” But if the majority of people are like, “I have questions,” or, “I don’t understand,” then maybe you take like an extra day or two to explain it better, and then... Because you do have a schedule that you have to keep, but at the same time you want to make sure there’s understanding.” (NOS/NOSI Interview Pre)

During the course, his demo lesson plan showed that he planned his lesson based on current curriculum. He clearly explained his objective as an expected outcome, which was “Students will be able to determine if a chemical or a physical change has occurred by observation.” According to teaching videos and researcher field notes, Charlie started his teaching with giving objectives, which are identified in national and state standards.

At the end of the course, Charlie’s pedagogical discontentment survey showed that his discontentment related to science curriculum had been increased. For example, in his pre survey, Charlie’s discontentment level was “1” (which means no discontentment) related to the statement “Balancing personal science teaching goals with those of state and national standards.” At the end, his discontentment level was “2” (which means slight discontentment). Likewise, he had more discontentment at the end related to the statement “Integrating NOS, throughout the curriculum.” His discontentment level changed from 2 to 3 (which means from slight to moderate discontentment)

Like in his pre understanding about knowledge of science curriculum, it was very hard to know to what extent he changed his knowledge about this aspect of PCK. His post CoRe also showed why he chose big ideas and why those ideas are important for students to know. These responses give us some hints to understand Charlie’s knowledge about science curriculum.

> Question: What do you intend the students to learn about this idea?
>
> Charlie: “Science is tentative and non-stagnant. This is important because is allows for previous theories and ideas to undergo changes as we learn more about how the world works.” (CoRe Post)

Question: Your first idea is tentativeness. Could you please tell me about why this is important for the students to learn it?

Charlie: "I think it's important because without the idea of science being tentative, then everything that we thought was correct is solid, there's no change in it, so why would we look at the area any further. So without it being tentative, there's no room for improvement or advancement." (CoRe Post Interview)

Question: Your second idea is subjectivity. Why is it important for students to learn it?

Charlie: "It's important for students to know that science is subjective because not everybody gets the same results. It was also stated in the science standards in our lesson plans. If you don't understand that, people coming from different backgrounds and different information is provided to them, then why would you collaborate? Why would his answer be okay but my answer wouldn't be okay? So, it's just important to know that collaboration is due to subjectivity, and just because his answer isn't the same as yours doesn't mean that you're wrong." (CoRe Post Interview)

In conclusion, as explained earlier, it is very hard to understand Charlie's knowledge of science curriculum by using NOS and NOSI aspects as big ideas in the CoRe survey. It can be said that he did not talk about science curriculum, or national/state standards. The only point that we looked at his understanding about science curriculum was the reasons why he chose his big ideas for students to know. According to those results, he was mostly aware of the importance of those big ideas for students to learn, and he apparently had enough knowledge about teaching science content.

Knowledge of Students' Understanding of Science

As explained in Chapter II, to employ PCK effectively, teachers must have knowledge about what students know about a topic and areas of likely difficulty. This component of PCK includes knowledge of students' conceptions of particular topics, learning difficulties, motivation, and diversity in ability, learning style, interest, developmental level, and need. Charlie's knowledge of students' understanding of science was analyzed in two sub categories: "Knowledge of requirements for learning", and "Teachers' knowledge of areas of student difficulty."

According to analysis, at the beginning of the program, Charlie clearly had a problem teaching science to younger student. He wanted to teach science in at least the college level. He believed that students need to have some prior knowledge to fully understand a concept. Otherwise, the concepts might be very abstract or students may lack any connection to their common experiences. For example, related to his first big idea "tentativeness," Charlie thought that tentativeness might be a new concept for students based on his own experience. Thus this concept might be very hard to get for students. They need to know something about it in their background, and they need to think about it before.

> Question: What difficulties/limitations are connected with teaching tentativeness?

Charlie: “I believe that this idea will be limited by student age and it may be hard to deliver the message without inferring on their previous ideas about science being concrete.”

Question: What is your knowledge about students’ thinking which influences your teaching of this idea?

Charlie: “I don’t believe that they will have ever thought about this before. I don’t think that they will have been introduce to this word or concept or if they have then it was brief and without full understanding of what was happening.” (CoRe Pre)

Question: The question about the difficulties and limitations, connected with your teaching. And, you said that’s limited by the student age. What do you mean by saying that, what specific age is enough to learn this idea?

Charlie: “Well, I guess I was thinking that in more of like my ability to teach them, not their ability to learn. I would like to teach science to elder students like college level. And like I think I could relate to them better. And then, it’s just when I explain something, I have a lot of trouble like bringing it down. Like I understand it at a certain way. And like when I explain it, I have trouble taking like or substituting words. Like I would use larger words.

I would expect that they know somewhat of what they’re getting into. And like, I guess in — like if it was elementary, or middle school, or something, like I don’t know if I could — I could, it just takes a lot more effort for me.”

Question: What about specifically teaching tentativeness? What kind of difficulties might you have?

Charlie: "I was just thinking back to my own thing. I don't think they'll understand that like, "Oh, it's always changing." And like, and you teach them about something."

Question: Okay. So, what about your students' thinking, which influence your teaching? So, what do you know about your students' thinking?

Charlie: "Well, some of the things I don't think — like if I were to be like discussing the topic of electricity, like she was saying, I don't think they've ever thought about, "Oh, when I turn this light switch on, what's happening? So, like some of the concepts and some of the ideas that we'll touch on, I don't think they've ever like actually thought about it before. And so, there could be like words or concepts that are completely foreign to them. And so, before you can teach the concept, you have to teach the language. And then, you can go into the concept. But then, they probably have misconceptions or like previous things like I don't know. When we watched the video, why the moon is." (CoRe Follow-up Interview Pre)

Related to his second big idea "subjectivity," Charlie emphasized the importance of student age as a factor to learn a scientific concept. Also, he pointed how misconceptions are important for teaching and learning.

Question: What other factors influence your teaching of this idea?

Charlie: “There will be age factors and also they have limited knowledge to draw upon and so many may come to the same conclusion and it will no express the variances as well as hoped.” (CoRe Pre)

Question: What about your students’ thinking? What do you think about your students’ thinking which influence your teaching subjectivity?

Charlie: “So, as a student, I feel like they would think that the data supports an answer. And there’s a misconception that there’s an expected answer. So, just like the previous one. And so, I feel like they would try to make their data fit towards that expected answer. But really, the data is just, it’s raw. And it’s unbiased, and it’s our own personal like experiences, and backgrounds that shape which directions we want to push that data towards. Like you could argue that that data supports A, but I can argue that that data supports B. And we would both be valid as long as we can shape it and we can like make solid conclusions about why it supports A or B.” (CoRe Follow-up Interview Pre)

Related to his third big idea “Multiple Scientific Methods,” Charlie believed that students would come to class with a misconception about multiple scientific methods, and it is very hard to change it because they want to stay and hold their original ideas. He thought teachers need to know those misconceptions and try to change those conceptually.

Question: What difficulties/limitations are connected with teaching this idea?

Charlie: “I would assume that they have been taught the classical method of the scientific method and they will want to hold to that idea.”

Question: What is your knowledge about students’ thinking which influences your teaching of this idea?

Charlie: “Also, I believe that the eight grade level they have misconceived images of men in labs and doing experiments.”

Question: What other factors influence your teaching of this idea?

Charlie: “The need to hold onto their teachers’ lessons. There is a trust that the teacher knows and if I deviate from that they may be hesitant to move from their current position.”

Question: What about the difficulties? I mean, what kind of difficulties and limitations are connected with teaching multiple scientific methods?

Charlie: “Again, related to my own experience, I feel like they will have only looked at the scientific method. And when I was first like — well, you don’t have to do the scientific method, I was like, “Wait, wait, wait, but that’s how I’ve always done it. That’s how I’ve been learned.” And so, like people don’t want to make changes. People want to stay the same. And so, I mean, they’ll be like seventh, eighth graders, but they’re just as stubborn as anybody else. So, and like I’m a summer program teacher compared to their everyday like teacher. And so, they would have a little more loyalty or faith towards the other individual. And so, I can definitely see like, Well, my teacher says that, you know, this is how it’s done.”

Question: What is your knowledge about the students' thinking which influences your teaching? You said that eighth grade level, they have misconceptions. What do you mean?

Charlie: "Well, like when I was — when I thought of scientists, I thought of lab coat, goggles, like in a chemistry lab. Like that's what I thought of. I didn't think of, you know, the crazy bird lady out in the woods recording sounds or like, you know, the woman, or man, or whatever. And that's like digging in the garden because like they're doing their own science. It's not all laboratory and sterile, and clean, and like that's what I always thought it was. And so, like that's what I was — when they think of scientists, they're thinking the lab coat, like messing with chemicals, studying animals or something like that." (CoRe Follow-up Interview Pre)

According to analysis of his pre- pedagogical discontentment survey, Charlie has moderate and significant discontentment about knowledge of students' understandings in science. Here are some statements that showed his discontentment.

"Teaching science to students of lower ability levels." (Level: 4)

"Identifying students' prior science misconceptions." (Level: 3)

In conclusion, Charlie believed that science is learned best with hands-on experiences, and the misconceptions that are held by students are very important for teaching and learning science concepts.

Question: How do you think your students will learn science best?

Charlie: "I think it depends on the student. Like I said earlier about lecture versus hands-on experience. Some people, they learn in different ways, so

> like the best way to help them learn is to add variety so that you're touching base with all of the different ways of learning, so if you learn best with a lecture, I'm going to lecture for a little bit, and then we're going to do an activity, we're going to have a lab, we're going to go on a field trip. And that way everybody gets a little bit of what they need." (VNOS/VOSI Interview Pre)

Like in his pre understanding about this aspect of PCK, during the course, Charlie emphasized the importance of knowing students' prior knowledge and revealing their misconceptions. Here is an example from his one-hour micro-teaching reflection assignment.

> Question: Did you follow your lesson plan or deviate from it in places? Explain how you used your lesson plan and when/why you deviated from it. How will you need to revise your lesson plan?
>
> Charlie: "We followed the lesson during the opening and introduction of the lab. We began to deviate from in during the lab while we were listening to the students discuss their thoughts about what they thought the materials were. Once I heard everyone making guesses, I decided it would be interesting to have everyone write what they thought on the board. From there we used that to begin our discussion, we then returned to our lesson plan to discus proposed solutions and wrapped up the lesson at the "break time." Revision will need to be made on our lesson because we will need to add a design chart for the students to write down their

observations and guesses on the board so everything is more organized."

(One-hour Microteaching Reflection Assignment)

At the end of the program, as in his pre knowledge, Charlie pointed out the importance of prior knowledge and misconceptions that students mostly held about science content.

Related to his first big idea "Tentativeness," Charlie argued that teaching this concept is very hard because there are limited examples which show the concept of tentativeness.

> Question: What is your knowledge about students' thinking which influences your teaching of this idea?
>
> Charlie: "I assume that they wont know what tentativeness is and it will need to be defined. Also, they are limited in examples of how the world has changed. This will make it hard for them to conceptualize what it means to be tentative in science."
>
> Question: What other factors influence your teaching of this idea?
>
> Charlie: "They have trust in their teachers and in the ideas that they have formed based on limited information and understanding. It is hard to change a mind that is trusting in other sources and that holds it own misconception of what is."(CoRe Post)

Related to his second big idea "subjectivity," Charlie pointed out the importance of student age. He believed that readiness is very important, and he could only teach this aspect of NOS to elder students.

Question: What difficulties/limitations are connected with teaching this idea?

Charlie: "I believe that students' preconceptions about science being right or wrong will limit their understanding or acceptance of this idea."

Question: What is your knowledge about students' thinking which influences your teaching of this idea?

Charlie: "I know that when I was younger I held this idea that science gave absolute answers and I believe that some of my students share the same thought process. This could prove difficult to overcome."

Question: What other factors influence your teaching of this idea?

Charlie: Age of the student…do they understand what it means to be subjective? Trust…they have heard from peers and teachers that science is stationary/absolute and I will be telling the different…will they accept this?" (CoRe post)

Question: For the difficulties and limitations to teaching subjectivity, could you please talk a little bit about what do you mean on your survey?

Charlie: "Just that science, I know when I was younger, I was always like, I like science and math because there is one answer, like there's an expected answer. And through the course of my college career and learning these classes, that's not how it is. And so, just…"

Question: So, do you think that your students are going to come with this knowledge?

Charlie: “Yeah, I feel like they’ll come in and be like yes, you know it’s science, like there’s expected answers, like we know this, I just need to know it. But really, it’s like we think we know it, but we need to be able to go further.” (CoRe Follow-up Interview Post)

Related to his third big idea “multiple scientific methods,” Charlie thought that students are taught the scientific method is the accepted method of how to do science. Thus, it is very hard to change those existing concepts. He believed that teachers should show different methods like observations and inferences.

Question: What difficulties/limitations are connected with teaching this idea?

Charlie: “Students are taught the scientific method and this is the accepted method of how to do science. This will limit their acceptance of other methods that are equally as productive.”

Question: What is your knowledge about students’ thinking which influences your teaching of this idea?

Charlie: “I was once a believer that the scientific method was how one did science. I know how difficult it can be to accept that it is not a solve all protocol and that some science cannot be performed without using other methods. Also many methods are intertwining. Observation and inference is used during the scientific method.” (CoRe Post)

Related to his big fourth big idea “Questioning,” Charlie pointed out students should be aware of the importance of questioning in science.

Question: What difficulties/limitations are connected with teaching this idea?

Charlie: "Sometimes it is hard to phrase an appropriate question that gives enough focus while leaving space to expand the original idea. Also, a lot of lab procedures don't allow for questions until toward the end of lab…you don't know the purpose of the lab you simply do it."

Question: What is your knowledge about students' thinking which influences your teaching of this idea?

Charlie: "I believe that they may say you don't need a question to do science. So you can just do it." (CoRe Post)

According to analysis of Charlie's post pedagogical discontentment survey, he believed that he did not have any discontentment related to this aspect of PCK. Here are some statements, which showed his discontentment level of his knowledge of student understanding in science. When looking at his pre survey, his discontentment level is decreased which means he relied on himself related to knowledge of student understanding in science.

"Teaching science to students of lower ability levels." (Level: 1)

"Identifying students' prior science misconceptions." (Level: 2)

"Teaching science to students of higher ability level." (Level: 1)

In conclusion, Charlie believed that age, student misconceptions, and content itself (very abstract or hard to learn concepts) are very important to teach and learn a science concept. Also, he thought that it is necessarily required for students to have enough learning abilities and skills to fully understand a science concept.

Knowledge of Instructional Strategies

This component has 2 elements: "Subject Specific" and "Topic specific." Subject specific refers to general approaches to instruction that are consistent with the goals of science teaching in teachers' minds such as, learning cycles, conceptual change strategies, and inquiry-oriented instruction. On the other hand, topic specific strategies that apply to teaching particular topics within a domain of science: representations (e.g. illustrations, examples, models, or analogies), and activities (e.g. problems, demonstrations, simulations, investigations, or experiments.)

According to analysis of Charlie's pre CoRe survey, follow-up interview, and pedagogical discontentment survey, Charlie explained a couple of instructional strategies. First he talked about "self reflection" which should be used as an instructional strategy to eliminate student misconceptions like science is solid and absolute. He also talked about how different teaching strategies should be used for different situations and to different students.

> Question: What other factors influence your teaching of this idea?
>
> Charlie: "Self-reflection, looking back I always had this idea that science was solid and unplayable. That there is one answer and that's it. I was shown otherwise." (CoRe Pre)
>
> Question: What other factors influence your teaching? I mean, you said that self-reflection. What do you mean by saying that?
>
> Charlie: "I would say it goes back to like them not understanding that it can change. Because like I said, when I was in grade school, like I always

was just like, “Okay, science is solid.” Like and I always was like, “I like science because there is one answer.” But there’s not one answer.”

That’d be the same kind of situation, like if that was my misconception, I know that a lot has changed since I’ve been in grade school, but like I would assume that.” (CoRe Follow-up Interview Pre)

Question: How do you think your students will learn science best?

Charlie: “I think it depends on the student. Like I said earlier about lecture versus hands-on experience. Some people, they learn in different ways, so like the best way to help them learn is to add variety so that you’re touching base with all of the different ways of learning, so if you learn best with a lecture, I’m going to lecture for a little bit, and then we’re going to do an activity, we’re going to have a lab, we’re going to go on a field trip. And that way everybody gets a little bit of what they need.” (VNOS/VOSI Interview Pre)

Lastly his pre pedagogical discontentment survey showed that he had discontentment about developing new strategies while teaching science and nature of science aspects.

“Developing strategies to teach nature of science.” (Level: 3)

“Orchestrating a successful balance between covering a wide range of material engendering deep student learning.” (Level: 2)

At the end of the program, Charlie believed that he can continually find better ways to teach science. He supported this view on his follow-up interview. He thought that science concepts should be taught via different strategies. It completely depends on what you are teaching.

> Charlie: "… I guess it's more like when it comes to something that's not inquiry based is when I have problems integrating it, just because of my own thought process of, well this would be better taught, not inquiry. And so when I read this, I take it as all inquiry based, not well this one can be inquiry but this one doesn't necessarily have to be as inquiry based, because I could totally do that. But if I were to take something, like I said, a dissection, or even if you had to do a PCR reaction, I wouldn't even begin to know how to make that inquiry based." (CoRe Follow-up Interview Post)

Charlie also believed that hands-on classroom activities are the best way of teaching science.

> Charlie: "…And that's what really drove it home for me, because your law is what is happening. Your theory is why is it happening. So, I would say that the hands on would be more impactful than anything." (Exit interview)

In conclusion, Charlie was aware of different teaching strategies, which were mostly explained in "Orientation Towards Teaching Science." Also, he argued that different science contexts need different teaching strategies. However, he preferred hands-on classroom activities and inquiry-oriented teaching as the most fruitful strategies to teach science.

Knowledge of Assessment in Science

Teachers' knowledge of assessment in science is an important component of PCK. This component is comprised of knowledge of the dimensions of science learning to assess, and knowledge of the method of science by which that learning can be assessed. This component includes knowledge of specific instruments, approaches, or activities.

In the first interview, when asking about how do you know your students' understanding or confusion, Charlie mostly talked about his experiences with what kind of questions should be asked to assess students' understanding.

> Question: How do you know when your students understand a concept that you've taught?
>
> Charlie: "You can look for that glazed look. I've had it before. But the best way I suppose is you ask. And, I know, a lot of them - I myself don't do it. If someone asks, "Do you understand that?" I'm not like, "No, I don't understand it at all." I don't ask questions - I'm actually really bad at it - and I should more, and I'm trying. But to ask, "Are there any questions?" Or perhaps if you notice that a particular student's grades aren't where they should be, or that they're grades are dropping as the course goes on. I mean you could set up a time and be like, "Do you need help with anything?" Or for your exams, or you can have a project that's like, "I want you to teach this," because the best way to learn it is to teach it. Um, and I know it's always said, but it is one hundred percent true. And

so I guess that would be a really good way to gauge understanding." (NOS/NOSI Interview Pre)

According to analysis of his pre CoRe survey, follow-up interview, and pedagogical discontentment survey, Charlie talked about different assessment techniques, which were exit questions, classroom discussions, building a model, designing an investigation, and pre-and post tests.

Question: How can you assess your students' understanding of tentativeness?

Charlie: Well, you could do the exit questions. Because that would give an assessment of like what you've learned. And I would hope that they'd be like, "Oh, that's different than what I thought it was. And I can't remember, but did they have like a pre-assessment with — so like, that would be the compare and contrast. I could give the pre-assessment and then the exit question." (CoRe Follow-up Interview Pre)

Question: What specific ways do you have of ascertaining students' understanding or confusion of subjectivity?

Charlie: "They will build me a model that meets all criteria and then present…then we will discuss the differences between each of the models and determine whose model is correct." (CoRe Pre)

Question: How can you understand your students' understanding or the confusion of subjectivity? I mean, how can you assess?

Charlie: "You could have like a class discussion. And you could start off with like their definition of what subjectivity is. So like, you just pose a question. So like, “So, we learned about this today, and we learned that science is subjective. What is subjective?” and have them answer that. And okay, I guess a lot of — I don’t have a lot of different teaching methods, but I would ask for examples of what specifically in their experiment shows subjectivity.” (CoRe Follow-up Interview Pre)

Question: What specific ways do you have of ascertaining students’ understanding or confusion of multiple scientific methods?

Charlie: “Give me a new definition of science and how is it different than when they came into the class. An example of doing science without doing an experiment.” (CoRe Pre)

Question: So, what specific ways also? I mean, to assess students’ understanding or confusion? [To make sure], you can understand your students’ thinking or your student confusion?

Charlie: “Yeah, because I feel like if I just ask them for their definition of science and like how’s that different from when they came in, then, that makes them do a self-reflection. And then, that makes them question their own thinking.

And then, by asking for an example of how you can do science without an experiment, they don’t necessarily have to give me like the classical example, but like their own example. So, they could use from the classroom, or they could make up their own scenario. And then, that would get them thinking about like doing science on their own without me necessarily saying, “Okay, here’s what you’re gonna look it. Here’s what I

> want you to do." Like so they're designing their own investigation while giving me the answer to my question." (CoRe Follow-up Interview Pre)

Although Charlie mentioned different assessment techniques, his pedagogical discontentment survey showed that Charlie had slight discontentment about assessing students' understandings from both traditional and alternative techniques. Also, he was uncomfortable assessing students' NOS understandings.

> "Monitoring student understanding through alternative forms of assessment." (Level: 3)
>
> "Assessing students' understandings from inquiry-based learning." (Level: 3)
>
> "Assessing students' nature of science understandings." (Level: 2)
>
> "Planning and using alternative methods of assessment." (Level: 2)
>
> "Monitoring student understanding through traditional assessment practices." (Level: 2)
>
> "Using assessment practices to modify science teaching." (Level: 2)
>
> "Assessing students' understandings from laboratory/hands-on learning." (Level:2)

During the course, Charlie tried to assess students' understanding of the concept that he taught in his demonstration and one-hour microteaching. According to analysis of those data, Charlie had assessment plans in his lesson plans. He planned to assess via question and answer session. However, he did not use those assessments techniques in his teachings.

Charlie: "Assessment: There will be a question and answer session where examples of changes are listed and the class will identify the changes as chemical or physical." (Demonstration Lesson Plan)

At the end of the program, there was no observable change of Charlie's knowledge of assessment in science. Like in his pre knowledge, he mostly argued that exit slips, question/answer sessions, and classroom discussions are used to assess students' understanding of NOS and NOSI aspects.

Question: What specific ways do you have of ascertaining students' understanding or confusion of tentativeness?

Charlie: "Exit slips and discussion about the importance of tentativeness and how this affects the way we think." (CoRe Post)

Question: So for the assessment part, you said exit slips and discussion might be used for how it affects the way we think. So, what do you mean by saying it??

Charlie: "So, the exit slip, the question would be how did tentativeness play a role in your investigation."

Question: Do you directly ask the question to students?

Charlie: "Correct. On the exit slip I would be. I would want them to answer that, but then when we discuss, because I want them to present their data on everything that we were discussing, I'd bring it up. I'd be like, was it the same every time or when you got information, did you have to change your investigation just a little bit?" (CoRe Follow-up Interview Post)

Question: What specific ways do you have of ascertaining students' understanding or confusion of subjectivity?

Charlie: "I will use discussion, question and answer to determine if my students know what it means to say science is subjective." (CoRe post)

Question: What specific ways do you have of ascertaining students' understanding or confusion of multiple scientific methods?

Charlie: "An exit ticket where they tell me what methods can be used to answer a question. How the methods a similar and how they differ. Give examples of a problem that needs scientific method and one that needs observation/inquiry." (CoRe Post)

Question: What specific ways do you have of ascertaining students' understanding or confusion of questioning in science?

Charlie: "Discussion about the importance of questions." (CoRe Post)

Charlie's post pedagogical discontentment survey showed that he still held the same discomfort level for assessing students understanding via alternative techniques. However, He thought that he did not have any discomfort to assess via traditional techniques.

"Monitoring student understanding through alternative forms of assessment." (Level: 3)

"Assessing students' nature of science understandings." (Level: 2)

"Planning and using alternative methods of assessment." (Level: 3)

"Monitoring student understanding through traditional assessment practices." (Level: 1)

"Assessing students' understandings from laboratory/hands-on learning." (Level:1)

In conclusion, Charlie did not change his knowledge of assessing students' understanding of science. He mostly talked about exit slips, classroom discussion, and question/answer session. Although Charlie felt comfortable using traditional assessment techniques, he did not talk about how those techniques might be used as an assessment of students' understanding or confusion.

Rose's PCK for NOS/NOSI

In this section, pre/post CoRe, pre/post Pedagogical discontentment surveys, follow up interviews, classroom artifacts, teaching philosophy, and exit interviews were analyzed to understand how pedagogical content knowledge for NOS/NOSI changed for Rose during the teacher development program.

Primary data sources for understanding participants' PCK for NOS/NOSI are pre and post CoRe and follow-up interviews. As explained in Chapter III, at the beginning of the second section of the whole program, each participant selected three big ideas from the targeted list of NOS or NOSI aspects in order to fill out the CoRe survey. Rose's big ideas were observation/inferences, data/evidence, and justification. At the end of the second section, each participant selected 5 big ideas (the first three ideas had to be the same as in pre-CoRe) from the targeted list of NOS or NOSI aspects. She added two more big ideas, which were multiple scientific methods and subjectivity on her post CoRe. During the second section (SCI 3030 NOS/NOSI course), classroom artifacts including demonstration lesson plans, teaching reflections, classroom videos, and researcher's field notes were analyzed for understanding the changes of her PCK for

NOS/NOSI during the program. Also, her pre and post pedagogical discontentment survey were analyzed to find out her discomfort level with regard to pedagogical content knowledge.

Orientation Towards Teaching Science

This aspect of PCK includes nine orientations, which are process, academic rigor, didactic, conceptual change, activity driven, discovery, project-based science, inquiry, and guided inquiry. At the beginning of the program, Rose would like to use inquiry based and activity driven orientations to teach NOS and NOSI aspects. She mostly held the idea of presenting information through lecture or discussion, and questions directed to students. Also, she thought that students learn best by doing and investigating. In this sense, she wanted to support students in defining and investigating problems, and drawing conclusions.

> Question: What teaching procedures will you use and what are the particular reasons for using these to engage with the idea of observation/inferences?
>
> Rose: "When first introducing these concepts, I would bring out a model of something and have students start jotting down what they see and different ideas about the object. Once they were done, I would begin a class discussion on what an observation/inference is and the different between them. Afterwards, I would have the students separate their notes into which were observations and what was inference. Following that I would have them practice a few more times on other models and then continue to incorporate it into lessons to follow." (CoRe Pre)

Question: Could you please explain what kind of teaching procedures are you going to use teaching observation/inferences? The question is: what are the reasons why this procedure is the best procedure? Or what else? Is there another procedure that can do this?

Rose: "There are probably many different ways to go about teaching something. I picked this particular way because I think it is very engaging. A teacher had used it on me by bringing in an object and having the students not knowing what the object is going to do. Making them observe and then inference what it was doing, most of my classmates and I would make a comment; but it was an inference, not an observation. It really made us differentiate the difference between the observation and the inference. It was really engaging because we didn't know what was going on and so we wanted to make more and more observations and then, in turn, they led to inferences. I picked that procedure because I felt it was the most engaging." (CoRe Follow-up Interview Pre)

Question: What teaching procedures will you use and what are the particular reasons for using these to engage with the idea of data/evidence?

Rose: "I would first introduce these concepts by listening to what the students already know about them. As a class, we could work toward defining the terms together, and then begin to practice what collecting data and evidence looks like. Continued practice in collecting data, as well as looking at other scientist data/evidence would be really important to follow." (CoRe Pre)

Question: For question seven, concepts based on evidence, you would first introduce these concepts by listening to what the students already know about them. Here you try to get what the students already know.

Rose: "Yes, dig into their prior knowledge. I would think by maybe even beginning a simple experiment or maybe I could lead it. To begin to practice that I could lead the experiment, and then they could help me collect the data and then we could, then, turn it into evidence. Then next time, they would do an experiment and they would collect their data and we would talk about it as a class; but just working towards the bigger picture." (CoRe Follow-up Interview Pre)

Question: What teaching procedures will you use and what are the particular reasons for using these to engage with the idea of justification?

Rose: "Teaching this would begin towards the end of an experiment. Once students completed their experiment and collecting data, I would ask them to draw a conclusion and justify it with evidence. After the students did this, we would work together on looking at what they did right in their justification and what they need to work on and include in the future. Following their own work, it would be important for them to look at the works of others to practice understanding what it looks like to justify your work and how to read and understand it." (CoRe Pre)

Question: Why do you think that? What do you want from these procedures? Why it is the best procedure giving the students these concepts?

Rose: "I chose this procedure because it would be after an experiment that they completed and they would have their data and their evidence and they would then complete the steps to analyzing that. They would then draw the justification themselves, so it would be their own work. Once they justified it and they drew their explanation, then we could work together on what were good points that they made and if I had questions or the student had questions, then they could see, "I made that in my justification as well" or "I might need that in my justification." But it is something that they are doing and they are experiencing. It also could be beneficial to maybe before beginning this, reading other justifications from other works, and so they see what it looks like and they can also see what it looks like to write one and experience it." (CoRe Follow-up Interview Pre)

In her pre discontentment survey, Rose mostly felt very comfortable to teach science with inquiry which parallels to her explanations on the CoRe.

"Ability to lead successful inquiry based activities/learning." (Level: 2)

"Preparing students to assume new roles as learners within inquiry based learning." (Level: 1)

"Using inquiry based teaching within all content areas." (Level: 1)

By analyzing her demonstration[4] and one-hour micro teaching lesson plans she tried to teach science through activity driven and conceptual change orientations. For example, her demonstration lesson plan showed that she would like to teach the concept of chemical change by using an activity driven orientation.

At the end of the program, Rose wanted to teach those NOS and NOSI aspects through activity driven, conceptual change, and mostly hands-on inquiry instruction. For example, she thought that the idea of "justification" might be taught with using an activity driven strategy. She wanted her students to participate in hands on activity used for discovery of how justification is important for making conclusions with using evidence.

> Question: What teaching procedures will you use and what are the particular reasons for using these to engage with the idea of observation/inference?
>
> Rose: "There are many ways to teach these concepts. First it would be beneficial to bring out a model of something and have students start jotting down what they see and different ideas about the object. Once they were done, I would begin a class discussion on what an observation/inference is and the differences between them. Afterwards, I would have the students separate their notes into which were observations and what was inference. Following that I would have them practice a few more times on other

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[4] Rose's demonstration lesson plan is provided in Appendix M.

models and then continue to incorporate it into lessons to follow." (CoRe Post)

Question: What teaching procedures will you use and what are the particular reasons for using these to engage with the idea of data/evidence?

Rose: "I would first introduce these concepts by listening to what the students already know about them. As a class, we could work toward defining the terms together, and then begin to practice what collecting data and evidence looks like. Continued practice in collecting data, as well as looking at other scientist data/evidence would be really important to follow." (CoRe Post)

Question: What teaching procedures will you use and what are the particular reasons for using these to engage with the idea of justification?

Rose: "Teaching this would begin towards the end of an experiment. Once students completed their experiment and collecting data, I would ask them to draw a conclusion and justify it with evidence. After the students did this, we would work together on looking at what they did right in their justification and what they need to work on and include in the future. Following their own work, it would be important for them to look at the works of others to practice understanding what it looks like to justify your work and how to read and understand it." (CoRe Post)

Question: What teaching procedures will you use and what are the particular reasons for using these to engage with the idea of multiple scientific methods?

Rose: "The teaching procedures that best fit teaching this idea is hands-on inquiry lessons, so students can experience the ideas of different methods." (CoRe Post)

Question: What teaching procedures will you use and what are the particular reasons for using these to engage with the idea of subjectivity?

Rose: "The best way to teach this concept would be a hands-on lab. A good idea is a dice activity with symbols of another language and the students need to figure out what they mean. By the end of it, the students gain an understanding of how they viewed the symbols in a different way than a person would who knew the other language, therefore people with different backgrounds can bring important information to situations." (CoRe Post)

In her post discontentment survey, like in the pre survey, Rose felt very comfortable to teach science with inquiry based and different methods.

"Ability to lead successful inquiry based activities/learning." (Level: 1)

"Preparing students to assume new roles as learners within inquiry based learning." (Level: 1)

"Using inquiry based teaching within all content areas." (Level: 1)

In conclusion, Rose was aware of using different orientations towards teaching NOS and NOSI. She mostly believed that NOS and NOSI aspects are taught through activity driven and inquiry based orientations. First, Rose wanted to know what her students have already known about those aspects, and engage them to explore those aspects with mostly student centered activities.

Knowledge of Science Curriculum

As explained in Chapter II, knowledge of science curriculum refers to teachers' knowledge about curriculum materials available for teaching particular subject matter as well as about both the horizontal and vertical curricula for a subject. This component is indicative of teacher understanding of the importance of topics relative to the curriculum as a whole.

At the beginning of the program, Rose explained the core ideas that she intended the students to learn, and why these ideas are important for them. However, Rose did not talk about how those ideas are related to science curriculum. It does not mean that she had naive views about this aspect of PCK. She showed that she clearly knew what she wanted to teach, and why those were important for students to learn, but not how they directly related to curriculum.

> Question: What do you intend the students to learn about this idea?
>
> Rose: "What is observation and inference, how these things are different and how they can be used in science."
>
> Question: Why it is important for students to know this?
>
> Rose: "This is important because for students to begin any activities in science, these are beginning ideas that are necessary for an experiment or data collection."

Question: What else do you know about this idea (that you do not intend students to know yet)?

Rose: "This difference between observation and inference. Why these things are important in science. How this type of information can be utilized." (CoRe Pre))

Question: Why do you think it is so important to teach observation/inferences?

Rose: "I think it is important for students to know this because there are going to be times in science when they're not necessarily be able to observe some things, like when they're studying the solar system or the study of the earth. They're going to need to know the difference between these things, but also it's important to understand because they need to know, even though they can't observe it directly, they should be able to make an inference based on characteristics that they have to understand the concept that they are really aiming to learn." (CoRe Follow-up Interview Pre)

Question: What do you intend the students to learn about this idea?

Rose: "What data and evidence is, the difference between them, but also their relationship together and how they are used in the realm of science.

Question: Why it is important for students to know this?

Rose: "These are important elements of science no matter what area you are studying. Not only do you need to know how to collect these things, but you also need to know how to read it when studying other scientists work."

Question: What else do you know about this idea (that you do not intend students to know yet)?

Rose: "All the different forms data can come in. How they can use data to act as evidence. How to collect data and/or read data." (CoRe Pre)

Question: Your second idea is for data and evidence. Why do you think that data and evidence is important for students?

Rose: "With science, whenever you are conducting any sort of experiment or exploration, they have to know how to collect the observation that they are making or the data they're seeing and then, in turn, use that as evidence. But again, it's almost like the observation/inference. They have to be able to separate what is data and how they can use that for evidence of their explanation or the argument they may be forming. I also think that is part of almost everything you do in science. That is a big part of it." (CoRe Follow-up Interview Pre)

Question: What do you intend the students to learn about this idea?

Rose: What it means to justify something and why this is important in the world of science.

Question: Why it is important for students to know this?

Rose: "This is another important element in science because student will both have to justify work of their own, as well as be able to understand justifications for the works of others."

Question: What else do you know about this idea (that you do not intend students to know yet)?

Rose: “How to form an argument for justification based on evidence. How to understand the justifications of others and how to apply it when studying the work of others.” (CoRe Pre)

Question: Your third idea is justification. You would like to teach justification and why this is important in the work. Why is this important in science?

Rose: “Justification is important because when the student is making a scientific claim or a conclusion, they have to be able to explain why they know it; and in order for another scientist to believe it and understand it, it needs to be a clear and sound justification. That’s why I think it’s important to start early in the year so they know what it looks like. They know that as they do their experiments and collect their data and use evidence, they are able to kind of wrap it all together in a justification as to why it worked or why it didn’t; or maybe answer the question that they were aiming for in the very beginning.” (CoRe Follow-up Interview Pre)

In Rose’s pedagogical discontentment survey, she did not have any discontentment about teaching personal goals and objectives within those of state and national standards. She was also very comfortable to integrate nature of science throughout the curriculum.

“Balancing personal science teaching goals with those of state and national standards.” (Level:2)

"Having sufficient science content knowledge to generate lessons." (Level:1)

"Integrating nature of science throughout the curriculum." (Level:2)

"Balancing personal science teaching goals with state and national testing requirements." (Level: 2)

In her pre VNOS/VOSI interview, Rose did talk about national standards. She believed that teachers should have a right to choose their own teaching strategies. However, teachers already have the freedom to choose their own teaching ways. Standards just only tell them what to teach with some limitations, as she mentioned in her last sentence below.

Question: In the public school setting, how do you decide what to teach or what not to teach?

Rose: "From what I've heard in public school setting, a lot of times you're given what to teach. You have the GLCEs that you follow or the Common Core standards, and so you do have the benchmarks that you have to teach to. But you also, I think depending on your resources and things like that, you may be able to teach it in a different way or teach different experiments and that sort of thing. But I do believe in the public school. We do have the GLCEs and the standards that we have to teach to." (VNOS/VOSI Interview Pre)

During the course, although there was not enough data to understand Rose's knowledge about science curriculum related to NOS and NOSI, she was aware her demonstration did not match her learning objective. This indicates whether her demonstration lesson plan had a specific learning objective or not, actual teaching experiences might end up completely different. However, she recognized her own mistake and how it could be modified in the next experiences.

> "I was fully prepared with my materials and everything was set up and ready to go for my demonstration. Both of my bottles had the appropriate amount of vinegar in them, with the balloon filled with baking soda attached and ready for observation. However, only one of the demonstration went as planned, but I was able to connect the demonstration that went wrong back to the learning objective." (Demonstration Reflection)

At the end of the program, as her pre CoRe survey, she clearly explained what she wanted to teach and why these ideas are important for students to learn. For all five ideas, Rose showed that she had good knowledge about goals and objectives for each. Also, related to fifth big idea, subjectivity, Rose explained that she has struggled about where she should start the lesson, and how much time she should spend on it.

> Question: What do you intend the students to learn about this idea?
>
> Rose: "Observation and inference, what they are and how these things are different and how they can be used in Science?"
>
> Question: Why it is important for students to know this?
>
> Rose: "This is important because for to gather information in science. Both of these are beginning ideas that are necessary for an experiment or data collection."

Question: What else do you know about this idea (that you do not intend students to know yet)?

Rose: “This difference between observation and inference. How this type of information can be utilized and the significance of it.” (CoRe Post)

Question: What do you intend the students to learn about this idea?

Rose: “What data and evidence is, the difference between them, but also their relationship together and how they are used in the realm of science.”

Question: Why it is important for students to know this?

Rose: “These are important elements of science no matter what area you are studying. Not only do you need to know how to collect these things, but you also need to know how to read it when studying other scientists work.”

Question: What else do you know about this idea (that you do not intend students to know yet)?

Rose: “All the different forms data can come in. How they can use data to act as evidence. How to collect data and/or read data.” (CoRe Post)

Question: What do you intend the students to learn about this idea?

Rose: “That there isn’t only one scientific method for students to use when exploring and conducting experiments.”

Question: Why it is important for students to know this?

Rose: “This is important because students all learn in different ways, therefore they need to know that they can solve the same problem in a way that best fits their learning mentality.”

Question: What else do you know about this idea (that you do not intend students to know yet)?

Rose: “I assume students will come in knowing the scientific method, but I don’t think they will understand there are multiple ways to use the parts within the scientific method.” (CoRe Post)

Question: What do you intend the students to learn about this idea?

Rose: “That every person comes to science with different ideas, perspectives and prior knowledge which affects how they interpret information.”

Question: Why it is important for students to know this?

Rose: “This is important because students need to respect the thoughts and ideas of other and understand that every person can bring unique thoughts to the same concepts, which is a good thing.”

Question: What else do you know about this idea (that you do not intend students to know yet)?

Rose: “Subjectivity can be influenced by prior knowledge, culture ideas and social aspects from someone’s life.” (CoRe Post)

Question: What do you think about the most difficult one for you to respond, of these eight actually? Not thinking about observation inference, just in general.

Rose: “Right. I think it might be what I intend my students to know, because it’s something that I just, I don’t know what they’re going to

> know, especially not having really taught yet, the older kids that are really into content. I have no idea where…"
>
> Rose: "I think that's my biggest one, is anticipating. I mean, especially because I have a lot of early childhood experience, and so I think I underestimate the older kids, especially middle school, if they're eighth grade."
>
> Rose: "I underestimate how much they're going to know and I'm not sure about it, and so I think that's the one that I would struggle with the most."
>
> (CoRe Follow-up Interview Post)

In her post pedagogical discontentment survey, there was little change, when compared to pre survey. The only difference was her discontentment level related to balancing personal science teaching goals with state and national testing requirements increased, which means she did not feel as comfortable to find a balance with those elements.

> "Balancing personal science teaching goals with those of state and national standards." (Level:2)
>
> "Having sufficient science content knowledge to generate lessons." (Level:1)
>
> "Integrating nature of science throughout the curriculum." (Level:2)
>
> "Balancing personal science teaching goals with state and national testing requirements." (Level: 3)

In conclusion, Rose was very comfortable about how and why she should teach the ideas of NOS and NOSI. Although she did struggle about national and state standards, which limit teachers she felt very comfortable with integrating nature of science throughout the curriculum.

Knowledge of Students' Understanding of Science

As explained in Chapter II, to employ PCK effectively, teachers must have knowledge about what students know about a topic and areas of likely difficulty. This component includes knowledge of students' conceptions of particular topics, learning difficulties, motivation, and diversity in ability, learning style, interest, developmental level, and need.

At the beginning of the program, Rose discussed difficulties and limitations connected to teaching ideas of NOS/NOSI, and other possible factors that influence the learning environment. Rose believed that knowing students, listening to their ideas, knowing their individual differences and the common misconceptions that students mostly have are the factors that highly influence her own teaching. Here are some examples from her surveys and interviews. Her responses are especially related to her second big idea, data/evidence, and were valuable in understanding her knowledge about students' understanding in science.

> Question: What difficulties/limitations are connected with teaching the idea of observation/inference?
>
> Rose: "Separating the ideas between observation and inference. Even though these are different forms of ideas, I think it may be difficult to get students to separate these to things, or get them to collect observations without adding any of their inferences." (CoRe Pre)

Question: What do you think about the difficulties and the limitations? Why is it so important for the teachers to be aware of difficulties and limitations for this idea?

Rose: "You have to be aware of difficulties and limitations for your students because you have to teach to the misconceptions. You are going to have students that don't understand it and you have to be able to help them understand why they're not understanding it in order to clarify it for them. As well as being able to teach beyond the students and understanding it, you have to be able to reach those students that aren't getting it and you have to know why it might be hard for them and difficult. In order to succeed in science they have to understand these concepts."

Question: Are there any other factors that influenced your teaching other than this?

Rose: "I would say that where my students are at would also influence my teaching, what concepts they are getting, maybe how they are getting it. Maybe I have more students in my class that aren't learning hands-on. Maybe they are more reading and writing or they read something and they can understand it. You take into account how your students learn best and what students learn which way."

Question: Knowing your students?

Rose: "Yes, knowing your students and how they learn best or maybe what levels they are at. Some students are going to be beyond. Some students are going to be lower. Some are going to be right in the middle. Also with the standards these days, I think a lot of concepts are learned for a test and then forgotten. That's why I think a lot of concepts need to be reviewed multiple times or incorporated into many different lessons and connected to, not only what they're learning in the classroom, but also to the outside world so students can really get a good, in-depth learning out of it." (CoRe Follow-up Interview Pre)

Question: What difficulties/limitations are connected with teaching the idea of data/evidence?

Rose: Getting students to understand that data isn't always the same as evidence or vice versa."

Question: What is your knowledge about students' thinking which influences your teaching of this idea?

Rose: "Experiencing what they're learning is most important. In order for students to understand data and evidence, they need to know what it is like to collect it and how it is done. By experiencing this, they will both know how to collect it, as well as read it when looking at data and evidence from other scientists."

Question: What other factors influence your teaching of this idea?

Rose: "Listening to students ideas in the classroom. It is important when teaching anything, that as a teacher you are listening to what students think about the concepts, how they understand them in their own terms and how they are able to apply them to the science in the classroom." (CoRe Pre)

Question: Our question was: what difficulties and limitations are connected to teaching with this teaching idea? You said, "Getting students to understand the data isn't always the same as evidence or vice versa." Why? How can you get it? How can you know that there are difficulties?

Rose: "Why the idea has difficulties? I think it may be easy to look at something – let's say you're doing an experiment of the rate of an object falling and you are timing it. The numbers, I would say, are the data that you are collecting, and then what you infer and gather from that then becomes the evidence that you use for your argument. But I think it could be easy to immediately go to say that the numbers, the raw data, is your evidence; whereas you first have to analyze it for it to then act as your evidence. I think they could easily jump back and forth between the two before fully understanding the different roles that they play in science."

Question: The next question is: what is your knowledge about your students' thinking? I want to ask you a general question about these questions. How important is it to know of your students, what they think?

Rose: "How important is it? It is probably one of the classrooms, actually, because not only are we teaching content in a classroom, you are teaching life lessons and you're teaching how to socialize, and along with those, their family is a huge factor. They might come to school hungry or in the same clothes or maybe in a fight with their family and that is going to affect what they are doing for that day. As a teacher, you need to understand where they are at within everything in the classroom because everything is going to affect everything else. If their parents are going through a divorce, they might be a little more upset and they're not going to be as focused on their work. If they're hungry, then they are going to be thinking about food instead of what they're learning. If one student learns better hands on, then they're not going to necessarily get the notes that you're taking on the board. If one student learns visually or by writing things out, they're not going to get something just by watching you do it. So there are many different factors."

Question: You are not just a teacher only giving the content?

Rose: "Right. It's not just pure content. There are many different factors and each of your students is an individual."

Question: It influences your teaching, right?

Rose: Yes.

Question: We asked you: what are other factors? Let's talk about that here. You gave the same answer; "listening to students' ideas in the classroom." How is this important?

Rose: "By listening to your students more than doing more of the talking, the ideas really become their own. With questioning you can get them to further ideas and then they are creating what you are talking about in class. They're leading the discussion; they're really making the learning their own, whereas if I sit there and tell them anything and they're just writing it down, they are not experiencing it. They're not using their own words to explain it. By listening to them or even actually when you're doing experiments or things and they say "What if we did this? What if we did that?" by doing that, it is also becoming their experiment and you are all working together. I think it really brings much more of a central unity in the classroom and it makes the learning a lot more in depth and powerful."

Question: But before you are teaching you are planning the lesson plans or something like that, what every teacher does, so what do you think about [ ]? How should it be flexible? Because listening to your students' ideas, just in this case, [ ] in this moment. Maybe you can sometimes change your lesson plans or something like that using different studies or something like that. What do you think – how should the lesson plan be flexible?

Rose: "A lesson plan is almost like a template, I think, for how the classroom should go. You have the content goals that you want to work towards. You have the activity you are going to do. You have questions, higher-order thinking questions. You have all these things to guide it, but the biggest part is your students. I might have goal A to get to that day, but they might not even get to the basic knowledge of it. So I think teaching is very flexible because it is all based off of your students. Maybe one day, as you were trying to get to goal A, they ask a question and it goes into a whole different experiment. I think once in a while it is important to let it go that way. You can't always let it go that way because of the teaching standards that we do have to reach at certain times; but I think allowing your teaching to be flexible is very important because it allows a student to be a part of the classroom as well, and they know that some days they can go and try something else and other days they have to focus more on the concepts we're aiming for."

Question: So what do you think about lesson plans? Do you think that you should clearly explain every second of the time in your lesson plans?

Rose: "It's not a bad idea to do that, but you have to be aware that it might not go that way when you're teaching it."

Question: Other factors influence your teaching? Individual differences?

Rose: "Yes, absolutely. That is why I also think that reflecting on your lesson plans, as well, after the activity – what went well? What didn't go well? What happened to make the lesson go in a different direction – that sort of thing. An in-depth guideline isn't terrible, especially when you are first beginning to teach because you might think "we'll do this and Tommy will ask that question right away," but he might not. So having everything written out right away definitely isn't a bad idea, but flexibility is an important factor." (CoRe Follow-up Interview Pre)

Question: What difficulties/limitations are connected with teaching the idea of justification?

Rose: "A hard part of this could be getting students to fully justify their work completely as well as understanding the work of others. It will also require them to incorporate working with their evidence and applying it to their justification."

Question: What is your knowledge about students' thinking which influences your teaching of this idea?

Rose: "I believe students learn best when they can explore what they are thinking. That is why I think teaching something is best done hands on."

Question: What other factors influence your teaching of this idea?

Rose: "Listening to students ideas in the classroom. It is important when teaching anything, that as a teacher you are listening to what students think about the concepts, how they understand them in their own terms and how they are able to apply them to the science in the classroom." (CoRe Pre)

In her pre pedagogical discontentment survey, Rose felt some discomfort in identifying students' prior misconceptions, and teaching science to students of higher ability levels, which mean she was aware of the importance of students' understanding in science, but she knows it is very hard to identify those understandings.

"Identifying students' prior science misconceptions. (Level: 2)

"Teaching science to students of higher ability levels." (Level: 3)

"Adapting science teaching strategies to reach ability levels of all students." (Level: 3)

Question: what do you think about teaching different levels?

Rose: "I just think that is the hardest thing to plan for because you don't know where your student is going to be at. Even though you might think that you are teaching something very clear, it might not be very clear to some students. I just think that is the biggest thing that is the most up in the air because something that I might find very easy to understand, my students might not all. I also have to be prepared to be able to keep the students that excel engaged, but also help the ones that need more help or vice versa – making sure if the kids don't understand it, they're not going to disrupt the class and they still stay engaged to work towards it. I just think that's the biggest unknown factor to work with in a classroom before you get to know your students." (CoRe Follow-up Interview Pre)

During the course, there was no data that contributed to an understanding Rose's knowledge of students' understanding in science.

At the end of the program, as in her pre understanding, Rose mostly talked about the importance of knowing the students, their misconceptions, their prior knowledge, and their needs by listening to them in the classroom. She believed that this is one of the most important factors for teaching and learning science concepts.

Question: What difficulties/limitations are connected with teaching the idea of observation/inference?

Rose: "Separating the concepts of observation and inference. These different forms of ideas are very similar, so I think it may be difficult to get students to separate these to things, or get them to collect observations without adding any of their inferences." (CoRe Post)

Question: What is your knowledge about students' thinking which influences your teaching of this idea?

Rose: “Experiencing what they’re learning is most important. In order for students to understand data and evidence, they need to know what it is like to collect it and how it is done. By experiencing this, they will both know how to collect it, as well as read it when looking at data and evidence from other scientists.”

Question: What other factors influence your teaching of this idea?

Rose: “Listening to students ideas in the classroom. It is important when teaching anything, that as a teacher you are listening to what students think about the concepts, how they understand them in their own terms and how they are able to apply them to the science in the classroom.” (CoRe Post)

Question: When you look at your response to question seven, what teaching procedures were used and why. So you picked these techniques actually, these procedures, to teach it. So why did you choose it?

Rose: “I like talking about introducing, to find out what they’re to know. I think you always have to know what students know before you teach them new things, because if they have misconceptions, if they have prior knowledge, that’s going to be the base of what you’re teaching. If they have misconceptions, you have to fix those before you build on them. So, I think that’s a good place to start, and then again, if you define these terms as a class together it becomes their definitions.” (CoRe Follow-up Interview Post)

Question: What difficulties/limitations are connected with teaching this idea?

Rose: "A hard part of this could be getting students to fully justify their work completely as well as understanding the work of others. It will also require them to incorporate working with their evidence and applying it to their justification." (CoRe Post)

Question: What do you intend the students to learn about the idea of multiple scientific methods?

Rose: "That there isn't only one scientific method for students to use when exploring and conducting experiments."

Question: Why it is important for students to know this?

Rose: This is important because students all learn in different ways, therefore they need to know that they can solve the same problem in a way that best fits their learning mentality.

Question: What else do you know about this idea (that you do not intend students to know yet)?

Rose: I assume students will come in knowing the scientific method, but I don't think they will understand there are multiple ways to use the parts within the scientific method."

Question: What difficulties/limitations are connected with teaching this idea?

Rose: "One limitation with teaching this concept would be the time frame because I think it would be great to let them experience setting up their own method but schools usually have shorter science time periods." (CoRe Post)

Question: What difficulties/limitations are connected with teaching the subjectivity?

Rose: "This may be difficult for students to understand because depending on the age, students can be very self-centered oriented, so it may be hard to get them to fully understand that other people can experience the same concepts in different ways and that all of this is okay." (CoRe Post)

Question: Which question is the most important for you as a teacher?

Rose: "I think it would be what is your knowledge about student thinking that influences your teaching, because I mean your class is really based on your students, because you could do - you know I could walk in with one method of teaching, the procedures that I want to do, and it might work great one year, but then the next year, if I don't get to know my students and get to know the thinking they have, their learning styles, it might not work at all. And so I think a lot of your teaching needs to be based on your students' thinking and how they think and how they learn, before you can lead them and teach them. So I think it has to be based around a lot of your students." (CoRe follow-up Interview Post)

In her pedagogical discontentment survey, Rose still had some discomfort about teaching science to the ability level of students because she did not believe in her own level of content knowledge.

> "Orchestrating a balance between the needs of both high and low ability level students." (Level: 3)
>
> "Adapting science teaching strategies to reach ability levels of all students." (Level:3)
>
> Question: the ability levels, you have a little bit of a struggle still?
>
> Rose: "That's the one that I just worry about because I mean, there's - even making these lessons. At first, I was worried about not having enough information, and then I found out we had a lot of that information. So, there's just so much to teach at the basic level, but then to kind of have to incorporate the higher level and the lower level, and being - most of the time, you're going to be one teacher in a classroom with K-12 students, and so that's just one that worries me, because I want to be able to teach all my students where they're at. I want to be able to give them the best learning possible, and so being able to do that for all levels is just something that I worry is going to be kind of difficult." (CoRe Follow-up Interview Pre)

In conclusion, Rose believed that teachers' knowledge about their students understandings of science is one of the most influential factors for teaching science. She thought that if a teacher listens to his/her students' ideas, and identify their prior knowledge and misconceptions, learning and teaching might be more effective and meaningful. Teachers can build on their teaching based on their students' understandings and needs for learning.

Knowledge of Instructional Strategies

As explained in Chapter II, this component includes subject specific and topic specific strategies. Subject specific refers to general approaches to instruction that are consistent with the goals of science teaching in teachers' minds such as, learning cycles, conceptual change strategies, and inquiry-oriented instructions. On the other hand, topic specific strategies apply to teaching particular topics within a domain of science: representations, and activities, like illustrations, models, analogies, or problems, demonstrations, and simulations.

At the beginning of the program, Rose believed that students learn best through hands-on and inquiry-oriented instruction. When she thought about topic specific, she mostly preferred teaching NOS/NOSI aspects via representation and activities like making models, analogies, and demonstrations.

> Question: How do your students learn science best? I mean you have already talked about that, but talk about specifically science.
>
> Rose: "Science best, I believe, is best learned hands-on, and inquiry based with the students exploring on their own. But I think it's also important to teach to different learning styles because some students are hands-on learners; some students learn by reading it, by writing it. And so that's why I think it's important in a science…"
>
> Question: Do you mean individual differences?
>
> Rose: "Yes. But in a science classroom to have the experiment, to have writing and reflecting on it, to also have the opportunity to read about it, to have different Power Points so they can see it. Students learn in all

different ways, but the more learning styles you can reach, the more students are going to learn from it." (NOS/NOSI Interview Pre)

Question: What is your knowledge about students' thinking which influences your teaching of the observation/inferences?

Rose: "I believe students learn best when they can explore what they are thinking. That is why I think teaching something is best done hands on."

Question: What other factors influence your teaching of this idea?

Rose: "Allowing the children to experience more then once and multiple times throughout the class. In order for something to be learned long term, it needs to be reviewed, repeated and practiced."

Question: What teaching procedures will you use and what are the particular reasons for using these to engage with this idea?

Rose: "When first introducing these concepts, I would bring out a model of something and have students start jotting down what they see and different ideas about the object. Once they were done, I would begin a class discussion on what an observation/inference is and the different between them. Afterwards, I would have the students separate their notes into which were observations and what was inference. Following that I would have them practice a few more times on other models and then continue to incorporate it into lessons to follow." (CoRe Pre)

Question: What is your knowledge about students' thinking which influences your teaching of the idea of justification?

Rose: “I believe students learn best when they can explore what they are thinking. That is why I think teaching something is best done hands on.” (CoRe Pre)

In her pre pedagogical discontentment survey, Rose struggled to develop new strategies for teaching NOS to students who have different ability levels.

“Adapting science teaching strategies to teach ability levels of all students.” (Level: 3)

“Developing strategies to teach nature of science.” (Level: 2)

During the course, demonstration, reflection, and microteaching reflection essays showed that Rose would like to use inquiry based instruction with activities and discussions in order to teach NOS and NOSI effectively. She believed that students learn science best via hands-on activities.

Question: Describe any other observations you made about your teaching. List at least two things you did well and two things you would like to improve.

Rose: “Some things I think did well was having the students observe parts of the demonstration before and after and I think it was a good idea to connect to back to real life and talking a little about how it relates to baking. However, if I were to do it again, I might open with a picture of a cake and ask why cakes rise during the baking. By doing this it would not only give me a starting and ending point, but it would allow for the students to relate more directly to chemical reactions. I would also try to engage all of the students during my questioning a bit better. So when I asked the question on what students thought happen, I would have all the students write their answer on a piece of paper or white board and then hold their answer up." (Demonstration Reflection)

Question: What areas do you feel most comfortable with? Why?

Rose: "I feel most comfortable with working with hands on activities with the students. I am most comfortable with this because it is the way I learn best, therefore I feel good about setting it up for the students." (Microteaching Reflection)

At the end of the program, like in her pre understandings, Rose believed that students learn best by doing, and experiencing. She thought that in order for meaningful learning, students should design their own experiments, and teachers should create a learning environment, which is based on hands-on inquiry lab instruction. Also, she believed that the lessons have to be reviewed, repeated, and practiced in order for effective teaching.

Rose: "… It is the responsibility of every teacher to equip students with the necessary knowledge and skills to help them succeed in school, as well as in life. I believe learning is best accomplished in positive settings, where the children are engaged in authentic, meaningful learning, which they can then relate and apply to their world around them. When this is accomplished children learn on a much deeper level, but also enjoy learning while it is happening." (Teaching Philosophy)

Question: What is your knowledge about students' thinking which influences your teaching of the idea of observation/inference?

Rose: “I believe students learn best when they are able to experience what they are learning. That is why I think teaching something is best done hands on.”

Question: What other factors influence your teaching of this idea?

Rose: “Allowing the children to experience more then once and multiple times throughout the class. In order for something to be learned long term, it needs to be reviewed, repeated, and practiced.”

Question: What teaching procedures will you use and what are the particular reasons for using these to engage with this idea?

Rose: “There are many ways to teach these concepts. First it would be beneficial to bring out a model of something and have students start jotting down what they see and different ideas about the object. Once they were done, I would begin a class discussion on what an observation/inference is and the different between them. Afterwards, I would have the students separate their notes into which were observations and what was inference. Following that I would have them practice a few more times on other models and then continue to incorporate it into lessons to follow.” (CoRe Post)

Question: Why do you think this is the best way of teaching observation/inferences?

Rose: “I think it’s - I do think it’s one of the better ways. I mean procedure wise, I think students learn best with experiencing things and practicing it, really reinforcing those ideas.” (CoRe Follow-up Interview Post)

Question: What is your knowledge about students' thinking which influences your teaching of the idea of data/evidence?

Rose: "Experiencing what they're learning is most important. In order for students to understand data and evidence, they need to know what it is like to collect it and how it is done. By experiencing this, they will both know how to collect it, as well as read it when looking at data and evidence from other scientists."

Question: What teaching procedures will you use and what are the particular reasons for using these to engage with this idea?

Rose: "I would first introduce these concepts by listening to what the students already know about them. As a class, we could work toward defining the terms together, and then begin to practice what collecting data and evidence looks like. Continued practice in collecting data, as well as looking at other scientist data/evidence would be really important to follow." (CoRe Post)

Question: Why did you choose this strategy to teach data/evidence?

Rose: "I like talking about introducing, to find out what they're to know. I think you always have to know what students know before you teach them new things, because if they have misconceptions, if they have prior knowledge, that's going to be the base of what you're teaching. If they have misconceptions, you have to fix those before you build on them. So, I think that's a good place to start, and then again, if you define these terms as a class together it becomes their definitions. They're working through understanding them in their own mind, as opposed to just memorizing a definition. And then it kind of just goes into practicing to reinforce the definitions, what we talked about as a class, things that I may have told them. It reinforces it in their minds and they get an actual feel for what it is. So it kind of takes the aspect of the reader/writer learner, with writing them down, talking about it, and then it takes advantage of the hands on learner, to apply what we've written on the board, notes that they've taken, into something real that they can see and do."

Question: So do you believe that these procedures can be applicable for every unit, every topic, or just on data and evidence?

Rose: "It depends on how much time you have in the class, especially in public schools, you don't have as much room in a science class. But I think there are ways to modify this to allow different things. Some things, if you can't actually work with it in class, maybe you could find something on the Internet, a different modular kind of thing that would, an interacting website, or you could watch a video and talk about it, like a real live video. There's ways to modify, to kind of bring in the real aspect if you can't always experience it or do a lab on it. I think there are ways to help it so they can relate a little bit more, but I think the relative outline of that is applicable. It just might not be doable, and so modifications might need to be made." (CoRe Follow-up Interview Post)

Question: What is your knowledge about students' thinking which influences your teaching of the idea of multiple methods of science?

Rose: “I think student learn best by applying their thoughts and thinking through hands on experiences.”

Question: What other factors influence your teaching of this idea?

Rose: “Listening to their ideas and allow them to listen to the ideas of others and work together as groups to create experiments and methods together.”

Question: What teaching procedures will you use and what are the particular reasons for using these to engage with this idea?

Rose: “The teaching procedures that best fit teaching this idea is hands-on inquiry lessons, so students can experience the ideas of different methods.” (CoRe Post)

Question: Could you please give me some detail about the different procedures you are going to use for teaching them multiple methods?

Rose: “I think the best way to teach this would be to give - I don’t have a specific lesson in mind, but to come across an activity that you could kind of allow the students to kind of make up their own - like find a problem, kind of what our instructor did. Kind of when she was sick one day and she said, how can we fix it? Come up with a simple lab where the students can figure out what to do, how they can fix it. You can have some students that might follow the step by step, scientific method, you have other students that wanted to go other different ways, but the best way for this, I think, is to show that one question or one idea or one problem can be studied by multiple different people, in multiple different ways. And so I think one way to do that would be to find an activity that students can kind of have a little bit of freedom in designing their own, and then coming together and reach the same sort of…"

Question: What is your knowledge about students' thinking which influences your teaching of the idea of subjectivity?

Rose: "I think for the best understanding, students need to experience this to understand it. They need to be exposed to something they might not understand, but that a person with a different background would understand better. By experiencing it, they will be able to understand it better."

Question: What teaching procedures will you use and what are the particular reasons for using these to engage with this idea?

Rose: "The best way to teach this concept would be a hands-on lab. A good idea is a dice activity with symbols of another language and the students needs to figure out what they mean. By the end of it, the students gain an understanding of how they viewed the symbols in a different way than a person would who knew they other language, therefore people with different backgrounds can bring important information to situations." (CoRe Post)

In her post pedagogical discontentment survey, Rose's discontentment level about developing strategies were the same as in her pre survey. Compared to other components of PCK, Rose felt more discomfort about adapting science teaching strategies to different ability levels of students for teaching NOS.

"Adapting science teaching strategies to teach ability levels of all students." (Level: 3)

"Developing strategies to teach nature of science." (Level: 2)

In conclusion, Rose's knowledge of instructional strategies were not considerably changed. Her understanding was the same when comparing her pre and post views. However, it can be said that Rose had very informed views about different teaching strategies especially for teaching NOS or NOSI aspects. She believed that science is learned best by doing, designing one's own experience, reviewing, repetition, and practices. She highly recommended hands-on lab activities for meaningful learning. She also pointed to the importance of models, analogies, and illustrations to teach NOS and NOSI aspects.

Knowledge of Assessment in Science

This component is comprised of knowledge of the dimensions of science learning to assess, and knowledge of the method of science by which that learning can be assessed. This component includes knowledge of specific instruments, approaches, or activities.

At the beginning of the program, analysis showed that Rose had very informed views about assessment methods for science. She pointed out how questioning and formative assessment techniques like discussions, reflections, or watching a student work are important, and how to use those in a lesson. She also talked about summative assessments and had very informed knowledge about those techniques.

Question: What specific ways do you have of ascertaining students' understanding or confusion of observation/inference?

Rose: "Questioning and formative assessments are very important in this area. Its important to not always be the one doing the talking in the classroom, but also listen to the students' ideas and definitions of the concepts being talked about. It is also important to make sure that the students are able to put the terms into words they understand and not only use text book definitions to define them." (CoRe Pre)

Question: Could you please talk about the formative assessment and what it means or how you can use it?

Rose: "In a classroom a formative assessment would almost be watching a student work and listening to their explanations or asking them questions or having them fill out an exit slip. It's called a formative assessment; it's not formal, whereas a summative assessment might be a test or a quiz and an exam of some sort. But I said "questioning in a formative assessment" because those are assessments that need to be done throughout the class, every class period, while those students are discussing their ideas and their thoughts. It is a way to gauge exactly what level your students are at."

Question: Using the formative assessment, how can you get that? How can you understand if your students get your teaching or what kind of [confusion?] (ph?) How can you get it by using the formative assessment?

Rose: "You can use it with talking. You can ask them questions and listen to their explanations. You could create questions, almost like learning goals, and ask them questions around those learning goals and just see their answers and really get them to explain different ideas to gauge if they are really getting the concepts that you are aiming for them to get." (CoRe Follow-up Interview Pre)

Question: What specific ways do you have of ascertaining students' understanding or confusion of data/evidence?

Rose: "Questioning and formative assessments are very important in this area. Its important to not always be the one doing the talking in the classroom, but also listen to the students ideas and definitions of the concepts being talked about. It is also important to make sure that the students are able to put the terms into words they understand and not only use text book definitions to define them." (CoRe Pre)

Question: For the assessing part, you gave the same answers as the first idea. Do you think the formative assessment and questioning are the most important things for all aspects, for all concepts?

Rose: "Questioning and formative assessments, I think, are very universal in any subject that you are teaching."

Question: Are there other assessment strategies for assessing student understanding besides these two? Formative is a huge thing.

Rose: "That's the thing; questioning and formative assessments are a very general way of collecting assessments, so there are many different ways it could look – talking it out, [exit] slips, writing, reflections. There are different ways to do it, but I still think they would fit into the questioning and formative assessment category." (CoRe Follow-up Interview Pre)

Question: How do you decide then how to move on to any topic in your class?

Rose: “I think that also...that might come from the teaching units that you’re provided, but it also I think comes from the students and where they’re at with their learning. It’s really important to observe your students and assess what they’re learning throughout what they’re doing because a lot of times they’re going to end up coming back to it in later years or maybe even later in your year, and so it’s very important to be sure that there’s an understanding. And once you know that your students - The majority of them have understood the concept you’ve taught then that’s a good time to move on, and if you have students that still aren’t really getting it, that might be a time that you meet with them after school or at other times to help them really get to where they need to be to move on as well.” (NOS/NOSI Follow-up Interview Pre)

Question: How do you know when your students understand a concept?

Rose: “Um, I think students really understand - You know they understand it, I would say during assessment, but when they can explain it to you in their own words, when they can express what something means in their own words as opposed to a textbook answer or a statement or (ph) definition, when they’re really able to..”

Question: How do you assess students understanding?

Rose: “Formal assessments are important I think throughout units, throughout lessons, where you’re observing them, maybe asking questions

> as they're doing their own work and gathering what they're pulling from their work that they're doing. And then at the end, more of a whole, summative assessment to gather everything that they learned from the entire unit or the entire project that you're working on, and how it's related to each other and different areas and how it's related to them or the natural world around them and different things like that." (NOS/NOSI Follow-up Interview Pre)

In her pedagogical discontentment survey, Rose felt comfortable using both traditional and alternative forms of assessment. She also believed that she could effectively assess students' NOS understandings from inquiry-based learning.

> "Monitoring student understanding through alternative forms of assessment." (Level: 2)
>
> "Assessing students' understanding from inquiry-based learning." (Level: 1)
>
> "Assessing students' nature of science understandings." (Level: 2)
>
> "Using assessment practices to modify science teaching." (Level:1)
>
> "Monitoring student understanding through traditional assessment practice." (Level:1)
>
> "Assessing students' understandings from laboratory/hands-on learning." (Level:2)

During the program, it was clear Rose had informed views about assessment in science. In different situations, like her demonstration or microteaching, she used various assessment techniques. She clearly explained students' understanding or confusion could be determined by using formative assessments like writing prompts, exit slips, or classroom discussions.

> "A formative assessment on the students' learning would be done during the class discussion first. Then a more in-depth formative assessment would be done as a small writing prompt or exit slip where the students would have to explain what they saw happening in the bottle, why it happened and how it relates to gas chemical reactions." (Demonstration Lesson Plan)
>
> "… I included the students in it by having them observe what they noticed about my balloon and bottle set up before, during and after the demonstration. Based off their attention span while doing my experiment and their participating in the discussion, I would say they enjoyed the demonstration and learned some things from it." (Demonstration Reflection)
>
> "I would also try to engage all of the students during my questioning a bit better. So when I asked the question on what students thought happened, I would have all the students write their answer on a piece of paper or white board and then hold their answer up. This would allow me to assess all of the students better before moving on to the rest of the lesson." (Demonstration Reflection)
>
> Question: What evidence do you have that the students achieved your expected learning outcomes? Be specific with examples from your teaching video.

Rose: "The evidence we have that the students achieved our expected learning outcome was the fact that they identified powder A and liquid A and powder C and liquid C as the solutions to the problem. They were able to identify the solution and used their observations to infer why these were the correct choices." (Microteaching Reflection)

Question: How did students understand these aspects? Give evidence for student learning.

Rose: "Students showed understanding of observation and inference when I posed the example, but they were still working on separating the two during their trials because they would put a gas formed under observation, when that actually should be a inference. A student in the class showed understanding of evidence because she discussed it when I was talking with her, however, we did not get a chance to discuss it with class as a whole." (Microteaching Reflection)

Question: How could you assess their understandings of the NOS and NOSI aspects?

Rose: "Observation, inference, data can all be formatively assessed during discussion and lab time, subjectivity, creativity, and tentativeness could be assessed in an exit slip and constantly revisited throughout the week." (Microteaching Reflection)

At the end of the program, although Rose gave the same responses as she did in the pre CoRe survey, she explained what she meant in the follow-up interview. As her pre understanding, Rose had very informed knowledge about assessment in science. Also, her post pedagogical discontentment survey showed that she did not have any discomfort related to assessing students' understanding or confusion about both in general and specifically for NOS/NOSI aspects.

> Question: What specific ways do you have of ascertaining students' understanding or confusion about observation/inferences?
>
> Rose: "Questioning and formative assessments are very important in this area. Its important to not always be the one doing the talking in the classroom, but also listen to the students' ideas and definitions of the concepts being talked about. It is also important to make sure that the students are able to put the terms into words they understand and not only use text book definitions to define them." (CoRe Post)
>
> Rose: "…I think students learn best with experiencing things and practicing it, really reinforcing those ideas. If they experience it, then it can become their own. With questioning, you know observing as a formative assessment, those sort of things, you're really gauging what the students know, you know their questions, what they want to know, maybe what they don't understand. It kind of goes along with it being a lot more student based and student led. And so I think in order to understand where they're at, and for the learning to be their own, as opposed to what you're just throwing at them, I think those are both really good strategies to use." (CoRe Follow-up Interview Post)
>
> Question: What specific ways do you have of ascertaining students' understanding or confusion about data/evidence?

Rose: “Questioning and formative assessments are very important in this area. Its important to not always be the one doing the talking in the classroom, but also listen to the students’ ideas and definitions of the concepts being talked about. It is also important to make sure that the students are able to put the terms into words they understand and not only use text book definitions to define them.” CoRe Post)

Question: For data and evidence, and observation inferences, how did you use formative assessments? What kind of formative assessments were you talking?

Rose: “That would definitely, I think I’d go with when they’re practicing and they’re collecting the data evidence, that would involve me walking around and interacting with them, figuring out what they’re collecting, how they’re interpreting it, the types of things they’re writing down. That would be a formative assessment for me, so I could take note of what students are really getting at, what students are maybe kind of sitting on the sidelines. What questions they’re asking, different things like that, those would be kind of the formative assessments. Maybe doing like an exit slip, things that aren’t necessarily graded but just kind of gauge more of their ideas, would be some formative assessments to use.” (CoRe Follow-up Interview Post)

“Monitoring student understanding through alternative forms of assessment.” (Level: 1)

"Assessing students' understanding from inquiry-based learning." (Level: 1)

"Assessing students' nature of science understandings." (Level: 2)

"Using assessment practices to modify science teaching." (Level:1)

"Monitoring student understanding through traditional assessment practice." (Level:1)

"Assessing students' understandings from laboratory/hands-on learning." (Level:1)

In conclusion, Rose started the program with informed knowledge about assessment in science, and she ended-up with the same informed view. She clearly explained different assessment techniques (Formative and Summative assessments) could be used in the different situations. She mostly pointed out the importance of formative assessment such as, classroom discussions, reflections, writing prompts, exit slips, or watching a student work in a science classroom.

Research Question 3

What factors mediate preservice teachers' abilities and teaching experiences to enact their PCK for NOS and NOSI?

According to analysis of Rose and Charlie's lesson plans and teaching videos for each day as partners, and their teaching reflections and exit interviews as individuals, this section describes, what factors mediate Rose and Charlie's abilities and teaching experiences to enact their PCK for NOS and NOSI. Analyses show that Rose and Charlie's knowledge of PCK components hugely affects translation of their understanding into practice. Also, additional factors such as, self-efficacy, subject matter knowledge, general pedagogical knowledge, research-course-teaching relationships, and lesson planning influence their classroom teaching. This section shows the possible factors, which influence Rose and Charlie's abilities and teaching practices to enact their PCK for NOS and NOSI.

Lesson Planning

As explained in Chapter III, Rose and Charlie tried to teach NOS and NOSI aspects on their teaching practices from Day One to Day Eight. During the those days, they wanted to teach "Empirical data and evidence," "Scientific theory/law," "Questioning," "Observation/Inferences," "Tentativeness," "Creativity," "Scientific Models," and "Multiple Scientific Methods." According to the analysis of teaching videos, classroom observation, and lesson plans, Rose and Charlie's Day One of teaching practices are summarized below in Table 5.

A similar instructional sequence was observed and analyzed during the Day Two, through four. As explained in earlier chapters, Rose and Charlie taught those same lesson plans in their second week to a different group of students. Rose and Charlie mostly began the lesson by reviewing the previous day's lessons, and asking students some questions to understand their' prior knowledge and assumptions of the activities and the topic of the lessons. They continued their lesson by introducing the activity or investigations with providing lab protocol. Then students conducted the activities, while Rose and Charlie guided them during the investigations. After the investigations, students discussed and shared their works with the classroom. Rose and Charlie pointed out NOS and NOSI aspects during the discussion.

Table 5

Summary of Lesson Plan for Day 1

Day 1	Activity	Description
	Question and Answer Students sharing ideas Overview of todays lesson	• Eliciting Students' Prior Knowledge • Leading the students in discussion, writing their thoughts on the board. • What is a model and how is it useful?
	Activity 1. "Cake Catastrophe" Activity driven Inquiry based	• Questioning drives all investigations. "How do you believe an investigation begins? What do you need? • What is and observation? What is an inference? • What evidence do you have?
	Discussion	During the discussion, students presented all their data on the board in front of the classroom. Each group shared their thoughts on how they think they can fix the cake using evidence they gathered from their observation/inferences during the lab. During the discussion, teachers asked; . What is evidence? What is it important? . What is subjectivity and creativity? How did you use those in your lab setting? . When you get the new information, what happened? What is tentativeness?
	Assessment: Exit Slip	• What happened in the bottle and how do you know? How can we apply this to our everyday lives?

Here, I provide an overview of Rose and Charlie's lesson plans for the four days of teaching. Rose and Charlie selected a chemistry topic, which was chemical reactions, and they wanted to teach the above NOS and NOSI aspects by integrating and embedding them into to this topic explicitly. For example, on Day One of Rose and Charlie's lesson plan (see Appendix N), they began with a connection to NGSS. Then, they explained the purpose, assumptions, and content learning outcomes of the lesson. In the next section, they presented NOS and NOSI learning outcomes, and how to connect their lesson to inquiry and NOS/SI. After those sections, they explained how to teach this lesson minute by minute. They planned their lesson with an opening, body, and closing. In the first stage, they tried to elicit students' prior knowledge by using a question and answer sessions. In the body stage, activities and experiments were explained along with what kind of teaching strategies that they will use. For the last stage, discussion and assessments were explained. The other three lesson plans were developed in a similar way.

As explained in Chapter III, Rose and Charlie developed four lesson plans. In order to develop effective lesson plan, Rose and Charlie created a first draft, and they did their second, third, and final drafts for each lesson plan based on the feedback given by the course instructor and researcher. Changes of those drafts also showed how the PCK components and other factors influenced developing those lesson plans. Here is an example of the changes of lesson plans from the first draft to the final version.

On the first draft of Lesson Plan One, Rose and Charlie simply indicated that they would like to teach empirical evidence, scientific models, scientific theories and laws, observation/inferences, creativity, and subjectivity. However, there was no detail about teaching procedure, activities, or assessment of those NOS/SI aspects. Based on the instructor and researcher's feedback, Rose and Charlie reshaped and added details on their next drafts. For example, when analyzing Lesson Plan Two, it was seen that the first draft was developed mostly as direct and didactic teaching. However, the final draft of Lesson Plan Two was developed based on inquiry and enabled students to explore the topic. Also, the first draft had some disadvantages, which could lead to students' misconceptions, but in final draft they eliminated those misconceptions and changed them. Lesson planning also helped to shape Rose and Charlie's actual teaching because they clearly explained how lesson-planning sessions influenced them and the importance of lesson planning on their teaching.

> Rose: "Well, by the time we taught with the lesson plans how many times we had to change them and edit them, I felt like I pretty much knew the plan, for the most part. So they were more just a guide for us. Because we had, I mean, we had designed them back in April and revised them and changed them, and then, first week of June we met up and we went through each lesson step-by-step and so I felt we were pretty well prepared in knowing what we wanted to plan for a lesson. (Rose Exit Interview)
>
> Charlie: "Well, we had our lesson plans. They were very detailed. And they gave us a very structured…This is how the day's going to go. We didn't end up using our lesson plans in that sense. We kind of just got there for the day. And it was like, "Okay. So, how do we want this to go?" And we had a brief, ten-minute discussion, as we were setting up. And

> then, that was—the rest of the day, just float from them. (Charlie Exit Interview)

Also, Charlie pointed out they needed to work on their own lesson plans because he believed that their lesson plans still did not have enough details.

> Charlie: “I definitely feel like I need to work on my lesson plans because we had some of the questions and did not—they weren’t things that were explicitly in our lesson plan.” (Charlie Exit Interview)

However, Rose and Charlie did not effectively teach NOS and NOSI aspects on the first week of teaching as they indicated they would in their lesson plan. So it can be said that Rose and Charlie needed more experience in creating lesson plans. For example, on Day Two, Rose and Charlie used some questions, which were not in their lesson plan, and those questions confused students. After Rose and Charlie realized their students were confused, they started to teach via lecture. However, their lesson plan was developed based on inquiry. Also, they did not discuss the NOS/SI aspects they had aimed to from their lesson plan. For example, they aimed to teach multiple scientific methods in the lesson plan, but they never touched on this aspect in their actual teaching. They explained this situation on their reflection essays.

> Rose: “Today, I was little bit nervous, but still prepared. I think I felt this way because we have spent so much time planning the lessons, but you still never know how it is going to go until you actually implement the lesson.” (Rose, Reflection Essay Day 1)

The details about using lesson plans during actual practice, and the connections between them will be provided in the next section under the related factors.

Knowledge of Science Curriculum

This component is indicative of teacher understanding of the importance of topics relative to the curriculum as a whole. This knowledge enables teachers to identify core concepts, modify activities, and eliminate misconceptions.

On the lesson plans, there was an overarching goal for the four teaching days. Rose and Charlie's big objective for those four days was "Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred." They also had a clarification statement which was "Examples of reactions could include burning sugar or steel wool, fat reacting with sodium hydroxide, and mixing zinc with hydrogen chloride." And they had an idea about assessment which was "Assessment is limited to analysis of the following properties: density, melting point, boiling point, solubility, flammability, and odor." Under the influence of the above overarching goal, every single lesson plan had specific "content," "NOS/NOSI," and "science practices" learning outcomes.

On the Lesson Plan One, Rose and Charlie clearly presented learning outcomes.

Content Learning Outcomes: Students will be able to identify evidence of chemical change through color, gas formation, solid formation, temperature change, and light. (Explained during the discussion, which was after the investigation. See prompt questions on the lesson plan in appendix N)

NOS Learning Outcomes: Scientific Knowledge is based on Empirical Evidence

- Science knowledge is based upon logical and conceptual connections between evidence and explanations. (MS-PS1-2)
- Students will explain the importance of having evidence to support claims.

- Students will describe how different results are possible from the same investigation.

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

- Laws are regularities or mathematical descriptions of natural phenomena. (MS-PS1-5)
- A law is a description of what is happening while a theory is an explanation of why or how it happens. Ball falling, how gravity works.
- Students will be able to describe the role of questions in guiding a scientific investigation.

NOSI Learning Outcomes: This lesson will clearly demonstrate inquiry and allow the students to differentiate between observation and inference. This lesson will also demonstrate science's subjective and tentative nature and the use of creativity within the investigation process.

Science Practices Outcomes: Developing and Using Models

Modeling in 6–8 builds on K–5 and progresses to developing, using and revising models to describe, test, and predict more abstract phenomena and design systems.

- Develop a model to predict and/or describe phenomena. (MS-PS1-1),(MS-PS1-4)
- Develop a model to describe unobservable mechanisms. (MS-PS1-5)

On Day One and Day Five, according to analysis of teaching videos and classroom observation, Rose and Charlie tried to teach most of the objectives that they wanted to reach in their lesson plan. They were completely successful in teaching students get content learning outcomes. At the end of the lesson, students successfully identified evidence of chemical change through color, gas formation, solid formation, temperature change, and light. They were also very successful in reaching NOS and NOSI learning outcomes such as, science is subjective, and scientific knowledge is based on observations and inferences. Students were able to describe the differences between observation and inferences, and the role of subjectivity in scientific knowledge.

> Charlie: "I feel the lesson went really well. We touched on all the objectives that we wanted to get at and introduced terms and ideas that are vital for the rest of the camp." (Charlie Day 1 Reflection)

However, it was seen that some of the objectives Rose and Charlie never touched on. For example, they aimed to teach the difference between scientific theories and laws, but they did not talk about those ideas during the lesson.

During the first day of the second week, Rose and Charlie taught the same lesson to ta second group of students. They appeared very confident in second week. Teaching the same lesson a second time apparently helped them to cover all the objectives that they wanted to reach. Also, they included a discussion about scientific theories and laws this time.

> Rose: "I was a lot more calm because of how well the lesson went last week. Even though it was a new group of students I figured it would still go well because of how well it went last week." (Rose Day 5 Reflection)

On the Lesson Plan Two, Rose and Charlie had clear objectives just like, they presented in their first Lesson Plan.

Content Learning Outcomes: Students will be able to apply prior knowledge to solve a problem, develop a protocol to reach a specific outcome. The students will be able to understand different properties of bouncy balls and how they're made by exploring how rubber reacts with acids and bases.

NOS Learning Outcomes: Scientific Knowledge is based on Empirical Evidence

- Science knowledge is based upon logical and conceptual connections between evidence and explanations. (MS-PS1-2)

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

- Laws are regularities or mathematical descriptions of natural phenomena. (MS-PS1-5)

NOSI Learning Outcomes: We would like to demonstrate how we can model the same problem that Europeans had with bringing the rubber across the oceans years ago, while also using prior knowledge and how to reverse the same problem. Students will also demonstrate how multiple methods, may produce the same result and/or reach similar conclusions.

Science Practices Outcomes: Analyzing and Interpreting Data

Analyzing data in 6–8 builds on K–5 and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.

- Analyze and interpret data to determine similarities and differences in findings. (MS-PS1-2)

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific knowledge, principles, and theories.

- Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints. (MS-PS1-6)

On Day 2, Rose and Charlie successfully taught and reached some learning objectives. However, like their first day, Rose and Charlie did not talk about some NOS/NOSI aspects such as multiple scientific methods. This NOSI aspect was their most specific and most important learning objective. During the lesson, Rose and Charlie mostly focused on content learning objectives (see the quotation below), not the NOS/NOSI objectives. At the end, they did not discuss about NOS/NOSI aspects. However, discussion about NOS/NOSI was apparently represented on the lesson plan.

> Rose: "Overall, the lesson was good, the students learned the objective. I was surprised that they wanted more depth in the content." (Rose Day 2 reflection)
>
> Charlie: "Next time, we have to make shorter the review session because we need to have more time to understand what the students understand." (Charlie Day 2 Reflection)

On Day Six, Rose and Charlie changed their teaching and touched on the NOS/NOSI learning objectives better. On this day, Rose and Charlie regularly pointed out and made the students aware that there are multiple scientific methods, which produce the same results/similar conclusion, or that using the same procedure might produce different results (subjectivity). It showed again practicing the same lesson helped these teachers to reach planned learning objectives successfully.

> Charlie: "Todays' lesson went very well because the students reached the learning goals and they were retaining knowledge." (Charlie Day 6 reflection)

On Lesson Plan Three, Rose and Charlie explained what they wanted students to learn from this lesson. Lesson Plan Three included the NOS and NOSI misconception of a scientific method. Rose and Charlie wanted to demonstrate a classical lab approach to experimentation and the scientific method. However, they had already presented on Day Two that there are multiple scientific methods. There is not only one way to do science.

Content Learning Outcomes: Students will be able to follow a classical lab protocol to reach a determined outcome. The students will then be able to discuss what took place within the system focusing on key points of chemical change, chemical structure, thermodynamics of the system, and the composition of physical properties.

NOS Learning Outcomes: Scientific Knowledge is based on Empirical Evidence

- Science knowledge is based upon logical and conceptual connections between evidence and explanations. (MS-PS1-2)

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

- Laws are regularities or mathematical descriptions of natural phenomena. (MS-PS1-5)

NOSI Learning Outcomes: We would like to demonstrate the classical lab approach to experimentation and the scientific method, while demonstrating that observation and inference can be intertwined with that methodology. Students will then implement a form of the scientific method in their own experiment designing their own investigation.

Science Practices Outcomes: Analyzing and Interpreting Data

Analyzing data in 6–8 builds on K–5 and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.

- Analyze and interpret data to determine similarities and differences in findings. (MS-PS1-2)

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific knowledge, principles, and theories.

- Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints. (MS-PS1-6)

On Day Three, students reached the content learning objectives. They were able to discuss the key points of chemical change, chemical structure, thermodynamics of the system, and the composition of physical properties. However, students were not able to reach the NOS/NOSI learning objectives. Rose and Charlie mostly touched emphasized the learning objectives of observation and inference, questioning, subjectivity, data/evidence, creativity, and scientific models. However, they did not successfully get the students to reach the learning objectives about multiple scientific methods and scientific theories.

On Day Seven, even though Rose and Charlie changed their lesson because of the time limitation, they still did not discuss the NOS/NOSI learning objectives for multiple scientific methods and scientific theories and laws. However, Charlie still thought that they reached all the objectives that they wanted.

> Charlie: "I think the lesson went well today. The students performed very well, and they came up with all the objectives that we wanted to reach."

On the Lesson Plan Four, as explained on the other lesson plans, Rose and Charlie wanted to reach almost the same learning objectives about NOS. However, they wanted the students to understand chemical change by making their own protocol based on the data and evidence that they had.

Content Learning Outcomes: Students will be able to identify evidence of chemical change. Students will apply knowledge to determine the mystery powder. Students will collect data making a claim as to what each powder is and support their claim with evidence from the investigation.

NOS Learning Outcomes: Scientific Knowledge is based on Empirical Evidence

- Science knowledge is based upon logical and conceptual connections between evidence and explanations. (MS-PS1-2)

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

Laws are regularities or mathematical descriptions of natural phenomena. (MS-PS1-5)

NOSI Learning Outcomes: This lesson will reinforce previous outcomes of NOSI/NOS. Students will set up an entire inquiry based investigation using observation and inference to determine if a chemical reaction has occurred. The students will use their knowledge of physical and chemical reactions to identify the mystery powder. They will then use evidence based reasoning and present their findings to the class.

Science Practices Outcomes: Analyzing and Interpreting Data

Analyzing data in 6–8 builds on K–5 and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.

- Analyze and interpret data to determine similarities and differences in findings. (MS-PS1-2)

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific knowledge, principles, and theories.

- Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints. (MS-PS1-6)

On Day 4 and Day 8, Rose and Charlie successfully reached most of the learning objectives that they wanted the students to learn. Rose and Charlie summarized all the lessons and objectives on Day Four and Day Eight. Students developed their own lab protocol and designed an investigation with the Rose and Charlie's guide. The students were able to analyze and interpreted data on the properties of substances before and after the substances interacted to determine if a chemical reaction has occurred. This indicated that Rose and Charlie reach their main overarching learning objective.

> Charlie: “I feel the students completed the objectives of the day and identified the mystery powders.” (Charlie Day 8 Reflection)

Orientation Towards Teaching Science

Orientation towards teaching science is one of the important factors, which directly influences teachers’ actual practices. As explained in Chapter I, nine orientations are identified to this element of PCK. According to analysis, Rose and Charlie mostly used “activity driven” orientations towards teaching NOS and NOSI. However, when analyzing their lesson plan, “open inquiry,” “discovery,” and “activity driven” orientations were mostly chosen to reach the learning objectives. Every single lesson, students were provided activities with structured protocol (activity driven). Only on the last day were students enabled to develop their own protocol (discovery). Rose and Charlie aimed to reach NOS and NOSI learning objectives with those activities. During the activities, Rose and Charlie usually asked some provocative questions to students in order to engage them into the activities. During the discussion sessions before and after the activities, Rose and Charlie mostly used “didactic” teaching orientations.

On Days One and Five, Rose and Charlie began the lesson with introducing some concepts through discussion with question/answer session. Questions were very direct like “What is a model in science? How is it useful?” After the students responded or not, Rose or Charlie explained about models to the whole class didactically. Then students started to make the cake model. Until investigations had been started, Rose and Charlie were mostly talking in front of the class, and while explaining the core concepts. However, the most important section of the lesson was doing an activity. Students were very active during the activities, and Rose and Charlie were walking around the tables and guided them to conduct the activity as explained in the lab protocol. Also, they asked some questions, which helped students to think about NOS/NOSI aspects, such as, “What is your observation?” and “How did you make your model?” At the end of the lesson, Rose and Charlie started the discussion with a question/answer session, and students shared their ideas, and presented their models with the class. Each group made different cake models using different substances, and Rose and Charlie talked about subjectivity through a didactic orientation.

Unlike Day One, Rose and Charlie had some difficulty in Day Five specifically during the discussion parts because the students in the second week were quieter than those in the first week, which indicated that different students need different teaching orientations.

> Charlie: “I think the lesson went well, but the students were less enthusiastic than the first weeks but they set to task and performed perfectly.” (Charlie Day 5 Reflection)
>
> Rose: “The biggest challenge today was trying to involve students who were apart of their groups but did not really participate with them. Charlie talked to them a lot but they still would not work with the group.” (Rose Day 5 Reflection)

On Days Two and Six, Rose and Charlie began the lesson with reviewing the previous day’s key points. There asked good questions, which connected the previous lesson and the current lesson such as, “What is observation? Where did you use the observation/inferences yesterday when you made the cake model?” During those question/answer sessions, Rose and Charlie mostly used a “didactic” orientation, in which the questions were asked to students directly, and students answered them. After having students discuss the question, Rose and Charlie the answer to the whole classroom. As happened in the Days One and Five above, students participated in hands-on activities used for measuring pH level of different substances. Students mostly engaged in activity to develop thinking process and integrated thinking skills which helped them to develop their understanding of NOS and NOSI concepts.

> Rose: “The students responded positively to our lesson and were very engaged. I think they responded this way because it was a very hands-on student led investigation, so they were able to explore and test things they wanted to, while also exploring what we wanted them to.” (Rose Day 2 Reflection)

On Day Three and Day Seven, Rose and Charlie started the lesson with reviewing the previous lesson as they did on the other days. During the reviewing sessions, Rose and Charlie started a discussion about NOS and NOSI aspects. Students were directly asked about “scientific models,” “observation and inference,” “subjectivity,” and “tentativeness.” This discussion was based on lecture, and it was very didactic since Rose and Charlie talked and explained those concepts in front of the class. After, Rose and Charlie began to explain new an activity by reading the protocol through lecturing. After that, students began an activity in which they made ice cream. During the activity, students were encouraged to answer the probing questions that were intended to help them connect the activity to the core ideas, thinking about how the salt affects the melting point of the water and changes the system. Students were actively participating in this hands-on activity. After the activity, Rose and Charlie started to discuss the activity thorough a question and answer session with question such as, "What is your conclusion based on your observation?"

> Rose: "The students responded positively to our lab again and at the end we even asked for feedback. They are really enjoying the labs because they get to participate in a lot of hands-on activities and aren't forced to just sit and listen to talking ad lecture." (Rose Day 3 Reflection)
>
> Charlie: "They like the lesson, we made ice cream. They were excited when they came up with the answers that we were looking for relating energy transfer and why the salt lowers freezing point and etc." (Charlie Day 7 Reflection)

On Day Four and Eight, unlike to the other days, this lesson was developed as "discovery" and "guided inquiry" orientation. After reviewing the previous lessons, students were asked to create their own investigation and write their own lab protocol. During this time, Rose and Charlie were circulating throughout the room and asked the students how they designed their lab. After students created their lab protocol, they began lab exploration. They wrote their process on the lab sheet recording the powder used, the observations, their inference as to which powder is which, why they believe their powder is what they say it is. This activity enabled the students to explore the nature of chemical reaction, and discover on their own patterns of which substances undergo a chemical reaction and which substances do not.

Charlie: “They loved the lesson, they told us on their exit ticket. I think they responded this way because they enjoyed the freedom to design the entire lab and they are proud of the work that they created. Gave them ownership.” (Charlie Day 4 Reflection)

Rose: “The lesson today went great! I think it was because the students were able to choose how they investigated each of the powders. Again it was a very hands-on lab and they were able to apply their knowledge from all week to their investigation.” (Rose Day 4 Reflection)

Rose: “They had a lot of fun and were fully engaged. I think this is so because they were able to make the lab their own and explore and apply their own knowledge.” (Rose Day 8 Reflection)

Students’ Understanding of Science

As explained previously, in order to employ effective science teaching, teachers must have knowledge about what students know about a topic and areas of likely difficulty. It includes knowledge of students’ conceptions of particular topics, learning difficulties, motivation, and diversity in ability, learning style, interest, developmental level, and need.

Rose and Charlie always began the lesson with eliciting students’ prior knowledge and common misconceptions about the topic. On the lesson plans, there was no clear section on the students’ requirements for learning and possible areas of student difficulty for the topic of chemical reactions and NOS/NOSI aspects. Thus, Rose and Charlie had some difficulties with understanding the students and managing the lesson.

The classroom as a group and each student, as individuals had different learning difficulties, needs, motivation, interest, and development level.

> Rose: "A group of students had their data and solution written out and I had them tell me about what was going on. They gave their solution but at first they could not tell me why they thought this would work. I led them through a thought process until they could distinguish how their two scenarios were different and why the solution would work where I had failed." (Rose Day 1 Reflection)

On Day One, the students were grouped and they performed their activity. One student in one of the groups was very active, and dominated to the group. It prevented other students from engaging in the activity. On this situation, Rose and Charlie let the student off with a warning. However, Charlie was aware of this problem and had a solution on his reflection essay.

> Charlie: "Some of the students were fidgeting with their balloons and not paying attention. A female student was very over powering within her group and did not let her group mate contribute much. Next time, I will seat the unengaged female student with a more assertive male student to help offset the dominating personality." (Charlie Day 1 Reflection)

Related to eliciting students' prior knowledge, Rose pointed out the importance of it to develop the lesson. They created their lesson plans without any teaching experience so their lesson plans and first teaching experiences had some problems regarding students' understandings and needs.

> Rose: "Next time, we will first gain a better understanding of their prior knowledge on acids and bases so we know whether we can move onto more in depth material regarding pH and hydrogen." (Rose Day 2 Reflection)

Since Rose and Charlie taught the same lessons twice, the different groups of students influenced their lesson. As explained above sections, first week students were very active and fully engaged the lesson. However, second week students were quieter and less engaged.

> Charlie: "This lesson was equally as effective compared to last week however I feel it went worse. The students complained about the smells and they had headaches. They are not inquisitive and thus they only did what was given on their data table and did not adventure into mixing solutions like week one's students." (Charlie Day 6 Reflection)
>
> Rose: "Our students, this week, are definitely having a harder time adjusting to our inquiry lessons. I am not sure if it's just because of what they are used to within their own classes or if they are just a quieter group of kids that need more structure, but we've definitely have had to work on staying up beat and motivating the students to keep investigating on their own." (Rose Day 6 Reflection)

Rose and Charlie figured out that every group of students needs different approaches, motivations, and interests.

> Rose: "I think it was just a great experience because it shows you how each class can vary, because we really didn't make any changes from

week 1 to week 2 because it went so well. There were a few minor tweaking things, but it just shows you how different students can react to the same lesson and how you just have to fit it to each student's needs. So I was happy with how that went. (Rose Exit Interview)

Charlie: "We let them know. "You can try mixing solutions. You can try doing whatever you want. It's your investigation." First week, they did that. And it helped generate questions. And so, they were like, "Wait. Why is this happening? Why is this happening?" And we're like, "What do you think's going on?" Or, "Well, that's cool. What's going on with this new thing that you did?" But in the second week, they didn't have any of that." (Charlie Exit Interview)

Instructional Strategies

Instructional strategies have two elements, which were subject specific and topic specific. Subject specific refers to general approaches to instruction that are consistent with the goals of science teaching in teachers' minds such as, learning cycles, conceptual change strategies, and inquiry oriented instruction. Topic Specific strategies apply to teaching particular topics within a domain of science: representations, and activities like illustrations, examples, models, problems, demonstrations, simulations, investigations, or experiments.

As explained in earlier sections, Rose and Charlie's knowledge of instructional strategies clearly made an influence on their lesson. They developed their lesson in the light of inquiry-based teaching via conceptual change strategies. On the specific topics, they used representations, activities, examples, models, and investigations. For example, while teaching "subjectivity" and "observation/inferences," Rose and Charlie used various instructional strategies such as investigations, activities, giving examples, and connecting their prior knowledge to the lesson.

Question: What aspects of NOS/NOSI did you use in your lesson?

Rose: We touched observation and inference, and subjectivity.

Question: Could you please talk about those? I mean how to integrate your lessons to these ideas.

Rose: "Well I know that we talked about subjectivity, especially it came out in our… what we did in class. We talked about the solution to how to fix our cake, which was our lesson, and one of the solutions of the lab though; one of them was baking soda and vinegar, and then water and baking powder. One of the students had talked about doing baking powder and water, as opposed to doing the baking soda and vinegar, because she knew that the vinegar brings out like a bad taste. I think that's - I think we incorporated, I'm pretty sure, subjectivity there, because she knew, by her experiences, that vinegar tasted bad, as opposed to someone else who would simply just pick vinegar and baking soda, or having the knowledge of what a cake - you know what kind of thing goes into baking a cake, or baking a cake with your mom or dad and knowing what things go in. I think we talked about subjectivity a little bit there, because their different experiences related to their different answers when we were kind of wrapping that up. That was one time, we learned about that. We talk about observation inference before many of the labs, before they start. Especially day one, and that was one of them, talking about with a balloon, when it's filling with - the fact that it fills with a gas, or that it inflates is the observation and the inference that it fills with gas. That sort of was a big one too because a lot of even the college students were writing down their inferences under the observations parts. We talked about that one there. I think we talked about creativity."

Question: So, you guys are going to talk about these ideas in the discussion part or doing the activities?

Rose: "A little bit of both. So, to set up the lab, we talk about them first, so like the observation inference. Other times throughout the discussion, walking around, that's when we bring up the oh, what are you collecting, how can that be used? And then kind of tie it into evidence. So it's a little bit of both. It depends on how the discussion goes in the beginning, what things we need to touch on before they go into their lab, and then what things we can pull out as they are working on their lab or as we're closing up the lab, in the discussion in the end." (Rose Exit Interview)

In another example from Day Two, Rose and Charlie introduced student to the "rubber" scenario (see Lesson Plan Two in Appendix O). After listening to the story, students were asked to do "think/pair/share" with the students at their table. This strategy helped students to think about a phenomenon, defend and argue their own ideas, and share those ideas with their friends.

Charlie: "Next week, we plan on incorporating small white boards into our discussion. This will allow us to incorporate more think/pair/share

> discussion because it was very helpful for each student." (Charlie Day 2 Reflection)

> Rose: "The students responded positively to our lesson and were very engaged. I think they responded this way because it was a very hands-on student led investigation, so they were able to explore and test things they wanted to, while also exploring what we wanted them to." (Rose Day 2 Reflection)

On Days Four and Eight, Rose and Charlie tried to teach science through playing a game. Students in both groups were very engaged in this activity and seemed to learn key concepts. During the "jeopardy" game, Rose and Charlie also had an opportunity to assess their students' understandings formatively.

> Charlie: "The day went excellent. There was 100% involvement and everyone reached the objectives. Jeopardy, though not well received first, turned out to be some of the kids' favorite thing." (Charlie Day 4 Reflection)

When Rose and Charlie had some problems because of their students' needs and learning differences, they tried to use new techniques to reach all students. By probing the different questions, providing new examples, illustrating a concept, enabling them to discover, or having them do experiments, it helped students to learn the objectives, easier and better. It can be said that this factor influenced these teachers' ability to teach science and NOS/NOSI.

> Rose: "The students were negative about the investigation and while learning they complained a lot. We had to have a classroom discussion

> about being an adult and dealing with things that are not always pleasant. I think we improved on applying leading questions, and simplifying complex concepts to something more understandable." (Rose Day 6 Reflection)

Assessment in Science

Rose and Charlie's knowledge of assessment in science had a clear impact on their effective teaching of NOS/NOSI. This component is comprised of knowledge of the dimensions of science learning to assess, which are conceptual understanding, interdisciplinary themes, scientific investigation and practical reasoning, and knowledge of the method of science, which are performance based, portfolios, journal entries, or written lab reports.

Rose and Charlie defined assessment in science within two categories: which were formative and summative assessment. According to analysis of their lesson plans, teaching videos, and exit interviews, they used many formative assessment techniques in their lessons such as discussions, working on models, drawings, and presenting lab reports.

For example, in Lesson One, Rose and Charlie used "exit slips." Students were asked, "What happened in the bottle and how do you know?" and "How can you apply this to our everyday lives?" Rose and Charlie explained how their plan was effective on their reflection essays.

> Question: What evidence do you have of students learning?
>
> Charlie: "We concluded with our solution and went over all of the different possible solutions. We discussed why some would work and why

others would not. This discussion or the answers to the discussion questions were provided via the students. We then went over some extra chemical properties/ chemical reaction signals. The students were engaged and provided appropriate feedback and could give examples of observations and inferences as well as relate understandings of subjectivity." (Charlie Day 1 Reflection)

Rose: "The students provided evidence of their learning after the investigation when we had them present their findings. They were able to take their trials and observations and use evidence to draw appropriate solutions to the problem we were working toward." (Rose Day 1 Reflection)

On Day Two, although there was no clear description about assessing students' understanding on the lesson plan, Rose and Charlie formatively assessed the students' understanding or confusion.

Charlie: "The students were able to relate the model of bouncy balls to the story about the boy peeing in the bucket. They were able to piece together the need of a base to keep the latex liquid and thus the acid to solidify the latex." (Charlie Day 2 Reflection)

Rose: "There was evidence of student learning during our questioning of the investigation, they were also making predictions of pH while mixing substances and they were able to test out mixing of liquid latex with acids and bases and conclude which substances we would need to keep latex liquid or solidify it." (Rose Day 2 Reflection)

Being able to effectively assess students' learning helps teachers to modify and develop the lesson based on students' confusion or understanding. On the second week of their teaching, Rose and Charlie determined common misconceptions that students might have from the last week, and they added some readjustment and tried to teach the lesson more effectively.

> Rose: "This week we had a better idea of how to organize and distinguish the rules of jeopardy. We also set it up so each group got the answer every question which increased student involvement and that worked out well." (Rose Day 8 Reflection)

Regarding teaching NOS/NOSI, Rose and Charlie explained how they assessed students' understanding or confusion, and how assessment impacted their teaching effectiveness.

> Charlie: "Experiment, and then or, demonstration. And we had been talking about limiting reactants. And it happens because there's carbon dioxide in there. And it's reacting with the Mentos. And so, they're retaining their knowledge. And they're giving evidence to support their claim, which is what we were talking about and . . .on the last day, they had to do everything on their own. So, they designed their own experiment or investigation. They had to use all the information that they've acquired throughout the previous three days to do the investigation. They've got to recall why baking soda and baking powder are different. And how one reacts with water. And one only reacts with vinegar. They had to recall information about their indicators. And so when we were going

> throughout our discussions – we'd be like—we'd be talking about it. And we'd bring up a point of, "When you were doing your investigation, did you have an idea about what you thought? Did that change as you furthered your investigation?" And you'd be like, "Now, what is this called? What part of science that we've been talking about would this fall under?" They could give us tentativeness. Or after some probing, they could give us the word "tentativeness." They'd describe it about, "Well, it can change." Or, "It doesn't stay the same." But they couldn't think of the word. And so, this says that they understand the idea of what tentativeness represents. But they may not have that word currently." (Charlie Exit Interview)

> Rose: "I think it flowed quite nicely with what we were talking about in the design of our lessons. You know, they were made, so we had to constantly talk about observation inferences. Students were reaching conclusions, so they had to gather evidence to support their claim and justify it." (Rose Exit Interview)

General Pedagogical Knowledge

General pedagogical knowledge is a teacher's knowledge of broad principles and strategies for classroom organization and management (Shulman, 1987). This knowledge transcends subject matter knowledge and represents comprehension of the duties and responsibilities of a teacher, as well as an understanding of the actions and activities necessary to meet and undertake those duties.

Rose and Charlie had some challenges with regards to classroom organization and management. Even though they taught the lesson together as partners, their first experience with kids was very different and hard.

> Rose: "The biggest challenge for today was organization I think. We had many different parts and transitions to our lab so it was difficult to keep up with the students, while also keeping the materials organized." (Rose Day 2 Reflection)

Rose pointed out time as a factor, which importantly influenced their classroom management and organization. During the two weeks teaching, they did a very good job with time management. They always had an alternative plan to arrange total time effectively.

> Rose: "Time management is important. We had planned to do one more test within the lesson, but once I noticed it was 11 o'clock we decided to omit one small part of it, to make sure we had time for closure, which was more important to the lesson." (Rose Day 2 Reflection)

Rose and Charlie sometimes struggled to make students get silent and focus on lesson, or to make students active and engaged in the lesson. They always tried to deal with those compete with those kinds of issues by using different techniques such as, lecture, changing seats, or playing a game.

> Charlie: "I gave my first disciplinary lecture today, two girls were arguing and would not stop when asked. After multiple attempts we had a talk in the hallway where we settled everything." (Charlie Day 6 Reflection)

Charlie: “I am less awkward when talking with the students as a whole and can handle some silent stares as they process or struggle with do I answer or just wait for him to move one.” (Charlie Day 7 Reflection)

Charlie: “I had issues trying to get them to create a decent data table. It took a lot of coaching and probing to get them to connect the data table to the protocol.” (Charlie Day 8 Reflection)

Rose: “I think today I did even better with encouraging the students. I ended up working with some the more difficult boys and instead of letting myself get frustrated and just giving them answers, I helped them pushed through and they did very well once they got started.” (Rose Day 8 Reflection)

As shown in the above quotes, Rose and Charlie successfully solved their classroom management and organization problems. As they explained in their exit interview, their first experience of teaching to eight graders and different groups of students influenced their teaching practices. They explained how they worked through those problems using their general pedagogical knowledge. They especially pointed out that different students need different general pedagogical approaches. There were several issues, which clearly impact to these teachers’ teaching practices.

Charlie: “Definitely dealing with conflict. Because the way that I want to respond isn’t necessarily a way that’s—it’s not unacceptable, but it’s not the best way to respond. Because, I mean, we’re dealing with eighth graders. And I want to respond in such ways like, “You’re adults. You have to work with each other. Get over it. And move on. Done.” But they don't respond very well with that. We had some conflict. And we had to take them outside. And talk with them. Because clearly, telling them that it needed to stop wasn't enough." (Charlie Exit Interview)

Rose: "I think the way the…the amount of time we put into our lessons definitely made me feel prepared. I still, going in to the lessons daily, I still was slightly nervous, but that was also just because I hadn't taught the lessons yet. So I could only be prepared as I planned for, but still with students, you never know how it's going to go. So I felt prepared, but I was still a little bit nervous." (Rose Exit Interview)

Rose: "By the end of the Week One, we were better than started to day 1, you know, giving them an idea, a better idea of where to put things. And then the other hard part was definitely Week Two. The kids would complain about anything. I mean they complained about their goggles and the gloves and the smells and…so it was hard to motivate them when I was feeling unmotivated. So that was a big challenge. But, I think on Day Four, I really worked on it because, actually, on Day Four, I ended up working with the four boys that were the most difficult, in a sense, and like, "I can't do this," "I don't know what to do," and well, I'm just going to go test them or like they weren't detailed enough. And so I really tried to work through and kept motivating them. But that was Week two; the hardest to stay motivated when my kids weren't motivated." (Rose Exit Interview)

> Rose: "Charlie actually made a comment one day during Week Two that he felt like we weren't that prepared; that we just go with the flow a lot. And I was like, well, it's kind of…I think that's kind of what teaching is because you don't know what to expect with the kids. You can make your lesson, you can plan for it, but you don't know if they're going to do it in five minutes or if they're going to explore and do it in 30 minutes." (Exit Interview)
>
> Charlie: "Get along with the students. But then, we had feedback. And they're like, "You guys need to be more fun." And so, maybe I'm not as fun as I think I am. And I feel like I'm fairly easygoing. So, when it comes to making messes and that kind of stuff, it doesn't ever—it doesn't really bother me if it gets a little chaotic, because it's science. And it's going to get chaotic. And you just kind of go with it." (Charlie Exit Interview)

Charlie also pointed out how he dealt with his own attitude in the face of a particularly difficult individual's problems.

> Charlie: "If you have a difficult individual, the closer you are to them or you're just being in proximity, I think, is what they call it. That just makes sense. If he's difficult, go and stand close to him, because your presence is going to be intimidating to his behavior. I mean, I walked around the classroom and stuff like that. But it was nothing I ever consciously thought of." (Charlie Exit Interview)

Subject Matter Knowledge

Rose and Charlie's subject matter knowledge of NOS/NOSI were presented under the Research Question One. This section focuses on how Rose and Charlie's knowledge of NOS/NOSI subject matter knowledge their teaching practices. Each lesson plan, except Lesson Four, had a clear section for connection to inquiry and NOS.

Connection to NOS and Inquiry:

- "During the Cake Catastrophe activity we will introduce evidence, observation, and inference. During the discussion post activity we will introduce the Law of Conservation of Mass and how it applies to the investigation, as well as detailing how subjectivity and tentativeness played a role during the investigation." (Lesson Plan 1)
- "Students will be given a scenario and have to apply their own prior knowledge to reach a solution. They will have to use creativity and modeling while working through their own inquiry of the situation." (Lesson Plan 2)
- "The students will be using observation skills to determine what is taking place within the system. They will then be expected to make inferences to describe their observations." (Lesson Plan 3)

As presented in earlier sections, Rose and Charlie successfully taught NOS/NOSI aspects with the help of their informed NOS and NOSI understandings (See the results of Research Question One). On their exit interview Rose and Charlie explained how they integrated and incorporated that knowledge into the chemical reaction lesson, and how it affected their teaching of NOS and NOSI. Rose identified how and why teaching of NOS/NOSI is important in science education.

> Rose: "I think in regards to the nature of science concepts and that sort of thing, I think it's important to teach as many of them as possible, especially with science being tentative, subjective, you know, the students know that I may think of this this way because I come from this area or a different area. You know, knowing about data and evidence and how that applies; justifying their claims that they're making based off their evidence. I mean I think those are all key points in to learning science and experiencing it and not just learning it from a textbook. It also is important, you know, learning about all those things because if you are researching or learning science you can't just take science as fact. You can't just say, "Oh well, he said it's right, so it's right." They also need to be able to analyze the data that they're looking at and read justifications and be able to make the decision for themselves is the sound conclusion; is a sound reasoning for the claim that they're making instead of just believing, you know, information that's thrown at them." (Rose Exit Interview)

When asked about teaching nature of science, Rose explained how and what parts of the NOS and NOSI they taught.

> Rose: "It really kind of…we had ideas of when to incorporate it, especially when we were doing different experiments, you know, talking about how we model the cake and that sort of thing. But other times it would also come up with just the kids talking in their discussion. Like "Well, I wouldn't use vinegar in the cake because it doesn't taste good."

"Well, how do you know that?" Like because of your prior knowledge, people are subjected to every piece of information, talking about one piece scale it one way, but the other one looked a different way. Well, maybe it's because long ago they made it this way and then science is tentative, so it's always changing and I mean, really, it just depends on what you're talking about and how it's going to best incorporate it. Because you can again, plan to incorporate in certain ways. But sometimes your students will pull it out themselves. Like we didn't even tell, I don't think Charlie even said it like telling them evidence to support their claim. Like we didn't tell them to support their claim. Like that's something that they had before, but so sometimes like they'll, like a few students would give you the information that you're looking for, but then you need to present it to the whole class and explain why it's important and why the evidence to support the claim as meaningful. And so, I mean, we plan different areas of where to incorporate it talking about the observation/inference we put on our data table, but there are also things that we just had to revisit the whole time when we were talking with them and questioning them and just having discussions with them. So we would plan to incorporate at different spots, but it also went off of a lot of the discussions and how we were interacting with the students." (Rose Exit Interview)

Rose: "We did tentative, so activity observation/inference. We talked about the law of conservation of energy. We did not talk about theories, though. Questioning…oh, Those ones. Tentative, subjectivity. We talked about evidence. We didn't talk about; we didn't specify empirical evidence, and then observation/inference and loss." (Rose Exit Interview)

It was also asked about how she felt when they were incorporating NOS and NOSI aspects into the lesson. Rose explained that she was a little nervous about those topics and when to incorporate them. During the teaching days, it flowed quite nicely with what they were talking about in the design of their lessons. They always constantly talk about observation and inferences, data and evidence, and subjectivity. Students were reaching conclusions, so they had to gather evidence to support their claim and justify it. So the way that they designed their lessons incorporated those ideas nicely. On the first week, the students supported their claims with evidence, and they built off that. On the other hand, in Week Two, they forgot to specify that wording, and so that was a difference in teaching.

> Rose: "I feel a little bit more confident with incorporating them and applying them in the classroom. I was very impressed, I mean, like I said, we planned for certain places, but when you plan for certain things, it's almost like, well, you just have to insert it there. But our transitions and our flow for incorporating them were very nice and you know, like I said, some of the students would actually bring them up and then we could build off of that as a class. So I definitely feel more confident with incorporated in the classroom because they're just concepts that we've been talking about most abstract. Like these are important and these are the…but to actually apply them to a classroom and they just fit so nicely, definitely helped my confidence in teaching them." (Rose Exit Interview)

Although Rose and Charlie successful taught NOS/NOSI, Rose was still worried about incorporating NOS/NOSI aspects into the classroom for her future teaching career.

> Rose: “I am little bit scared probably the incorporating the NOS and NOSI into my teaching and looking at how those lessons worked well in the classroom. How can I maybe adjust them to fit in a normal classroom, but also how to continually apply those concepts within science so the kids can understand them and take them as they move on in their science career?” (Rose Exit Interview)

The same question was asked to Charlie, and he explained how to integrate his knowledge into his teaching.

> Charlie: “I definitely think it’s important to talk about the negative words, like, “Proof,” and stuff like that. Because when you talk about proof, you get into the idea that if you’ve proved it, then, it’s proven. Why would I continue looking into it? Or researching it? And then that gets into the whole tentativeness. And that can connect with subjectivity, because you proved it this way. And then, I proved it this way. We both have different information. We both came to different conclusions. And then, later on down the road, someone—they’d be like, “Well, we have a lot more information now. It’s changed. I don’t believe any of you. And I’m getting at this answer. So, definitely talking about those core ideas of science always moving and never being stagnant. And then, being able to back up your claim with evidence. I would drive those points in, and we did during the camp. I feel like I do it kind of like we did our camp. We’d have our

general idea of what we'd want. But we're not going—I mean, I'm not going to give them a protocol that they need to follow. I want them to play with things. And figure things out and kind of gather their own connections about how it's working." (Charlie Exit Interview)

Question: What part of the nature of science did you use in your teaching?

Charlie: "We used observation and inference. We touched on subjectivity, and tentativeness, and we talked about the importance of a question. I don't know if we talked on creativity. But we did talk about theories and laws. I hit all of these except for socio-cultural influence. I don't think those two were explicit." (Charlie Exit Interview)

Charlie also talked about how NOS and NOSI are connected to each other.

Charlie: "The difference between nature of science and nature of science inquiry? I feel like they support each other. You can't really have one without the other. So, if you didn't have your question, what would you observe and infer? And if you didn't have your observation or inferences, what kind of data and evidence would you have? If you're counting cell viability, you're observing which ones are dead or alive. And that is your data. That is your evidence, your inference is—I would say it's related to your argumentation. They kind of go hand in hand, because you're—if I say, "This orange juice is sour," or whatever, I'm arguing my inference. And my inference is based on, "Oh, well, you know, it smells funny. If you test it, the pH is off." And so forth. So, I think they're all interrelated.

And they depend on each and every one to help hold the other up." (Charlie Exit Interview)

In addition, the concepts' difficulty itself influenced Rose and Charlie's teaching of NOS and NOSI because the students had a hard time understanding some concepts rather than other concepts such as theories/laws versus observation/inferences.

> Rose: "Correct. Yeah, we talked about laws, but we didn't talk about the differences of the theories and laws and socio-cultural value. So I think that might be a hard concept for students to understand." (Rose Exit Interview)

Teacher Self-Efficacy

In addition to all the other factors which influence teaching of NOS and NOSI, Rose and Charlie's self-efficacy towards teaching science was very important and had an impact on their teaching practices. According to analysis of researcher's classroom observations, teaching reflections and the teaching videos, Charlie had highly self-efficacy regarding the science content knowledge itself, but he had anxiety regarding the teaching of that content. On the other hand, Rose had high self-efficacy regarding to her teaching ability. She also had a very informed understanding about NOS and NOSI, as well as science content. Rose's teaching confidence resulted in her tending to dominate the lesson. However, this also helped Charlie learn to incorporate his knowledge into her teaching abilities. Rose's high self-efficacy was one of the most important factors of her success.

> Rose: "I hold myself to a very high standard, especially because I know that with teaching, my actions directly influence those of my students, my

teaching peers, people that I'm working with, so if I don't hold myself to high standards, it's going to then affect everyone around me. So I say, yes, that's a very high motivator." (Rose Exit Interview)

Rose: "The only hard thing with teaching this, you know, teaching inquiry based is that we were able to do it so nice because we had a two and half hour time period where as in the classroom, you're not going to have that much time. And so I think, you know, it's something that, as a teacher, I'll have to work on incorporating just throughout discussions and throughout activities. And then reapply it when we do have time for the labs because we're not always going to have time to do a big lab. And so it'll just be something that you'll have to talk about and discuss and then let them experience later on, but making sure they get, you know, you're discussing it and they're getting a chance to experience it and planning that time for both within my teaching." (Rose Exit Interview)

Both Rose and Charlie explained that the second week of teaching was better than first week because their self-efficacy increased thorough experiencing and teaching the same lesson previously.

Charlie: "I was comfortable with today's lesson. We had already completed this lesson before with great success and I was confident that it could happen again." (Charlie Day 5 Reflection)

Rose: "I was a lot more calm because of how well the lesson went last week. Even though it was a new group of students I figured it would still go well because of how well it went last week!" (Rose Day 5 Reflection)

When asked about their main strengths as a teacher, Rose pointed out her classroom management, interacting with students and her partner, and the ability to find an alternative plan in the face of struggling. Charlie pointed out his content knowledge and ability to ask different questions.

> Rose: As a teacher, I was proud of my classroom management, interacting with the students while they were working on their explorations, revisiting information that we forgot to discuss, while also keeping it relevant. For example, we forgot to talk about cross-contamination of materials while doing the lab, but were able to incorporate it during our closing discussion while doing a demonstration." (Rose Day 1 Reflection)
>
> Rose: "I think one of the strengths I have is kind of going with the flow. Oftentimes, you know, kind of just, you work with what you get, well what you have. Like some days we had certain things. Other days we didn't really plan for things. And so we had to get materials on the go. Or just kind of work with what we had. When time doesn't really cooperate, you just kind of got to twist your plans and adjust it a little bit. And so I think I do that really well." (Rose Exit Interview)
>
> Rose: "So I definitely feel more confident with incorporated in the classroom because they're just concepts that we've been talking about most abstract. Like these are important and these are the…but to actually apply them to a classroom and they just fit so nicely, definitely helped my confidence in teaching them." (Rose Exit Interview)

Charlie: "I think, because there's different ways I can apply the question. Probably what's going to stick with me the most is probably the confidence that the program gave me. Before I came in, I would never, ever go up in front of people and talk. Now, I'm definitely more confident within myself as not only an educator, but as an individual and as a teacher the confidence to voice my views." (Charlie Exit Interview)

Research, Course, and Teaching Relation

The last factor that was identified from this study was the effect of this whole program on their teaching practices. Analysis showed that the research, course, and teaching were well integrated and influenced Rose and Charlie's teaching of NOS/NOSI. As presented earlier in this Chapter, it was explained that the research and the course had a large impact on Rose and Charlie's NOSI and NOSI views as well as their pedagogical content knowledge of teaching NOS/NOSI aspects. Rose pointed out that practicing, lesson planning, and discussions after teaching were very important and impacted her teaching success.

Rose: "We had also practiced part of the lesson for day 1 and part of the lesson for day 2. And so those two, we definitely had a better idea of what we wanted to do. Day 3 and Day 4, we were a little bit more, you know, I needed to look over a little bit more and review it before we did it. But they were, it was a helpful guide and I think the more detailed we did it, helped us to be better prepared. In the future, I would actually probably add, though making – and this was one thing that my mentor had recommended – like making little note cards for questions that you want to

> ask to help with discussions or key points that you want to talk about to make sure you don't get off key or think students aren't giving you the feedback that you want or the answers or questions that you want; to make sure you hit those key points. I think that was one of the things. I just joined the discussion at times. I would get nervous and rush through it and we were missing our point. So we made it a point to review every day, which we hadn't really put in their lessons. We didn't plan to review at the beginning. But we ended up doing that and it worked out nicely. (Rose Exit Interview)

When asked about how the course effected the translation of their NOS/NOSI knowledge into the teaching practicum, Rose and Charlie explained:

> Rose: "Yeah, I mean we did a lot of, I mean we constantly talked about the questioning techniques. I was always…I was always making sure that I didn't ask a question that had like a yes or no answer. More open-ended questions, higher order thinking questions. I was always thinking of opportunities to incorporate the NOS and NOSI which I think we actually did a lot more than we, a lot more than I expected us to do. I was happy with how much we were able to incorporate it because I don't remember that happening a ton the year before when I observed. I don't remember that right. But I was always trying to look for ways to incorporate that into our lesson, especially because they apply it. They apply it very nicely. Obviously, that's why we wanted them. But to science and the real world and real thinking in those aspects. So yes, I was always thinking of what

would happen with the lessons and the questionings and all of the concepts and that sort of thing." (Rose Exit Interview)

Charlie: I can see why they're needed. Because without the research part, I don't feel like—I mean, I come from a very heavy science background. But for individuals who don't have the heavy science background I see as very beneficial to be like, "This is real science." "This is what you do on a day to day basis." Because I don't know if anybody would understand that without doing it. Just like I didn't understand—I don't come from teaching backgrounds, so, I didn't understand everything that was involved in teaching. Which is definitely what the course was needed for. And the lesson plan. It helped a lot to have that drilled in throughout the course. A lot of the information and material was repetitive to me, just because I had that other class with the same instructor. So, all the NOS, NOSI stuff that we talked about. I already had that from her lessons. And so, that was repetitive for me. But for other people, it may not have been. Even this whole teaching experience, this you have to bring it all together. So, I definitely see how they fit. (Charlie Exit interview)

CHAPTER V

CONCLUSION, DISCUSSION, AND IMPLICATIONS

This Chapter includes the following sections: (a) a conclusion of research findings; (b) a discussion of the findings in relation to the education literature presented in Chapter II and a discussion of how this study contributes to an understanding of the preservice teachers' PCK for NOS and NOSI; (c) implications of this research for the preparation of preservice science teachers and professional development for experienced teachers, as well as for future research; and (d) limitations of this study.

Conclusion

Research Question 1

The focus of the first research question is to identify Rose and Charlie's understandings of targeted NOS and NOSI aspects and how those views changed during the teacher development program called ExpeRTS. As shown in the Chapter IV, Charlie began the program with mixed views, while Rose had more accepted views of NOS and NOSI at the beginning of the program. Throughout the program, both students changed their understandings of almost all of the accepted NOS and NOSI aspects.

Related to the targeted aspects of NOS, Charlie made the most notable changes on tentativity of science and the differences and relationship between scientific theories and laws. On the other hand, he was unable to demonstrate change in his views on socio/cultural values in science (See Table 3). Charlie most often talked about and used the aspects of subjectivity and observation/inferences on his CoRe surveys and his teaching practicum. On his exit interview, he explained what NOS means to him:

> "Science is not experimentation. Experimentation is a part of it, but a lot of is investigation. And a lot of it has to do with your observation/ inference."

Related to targeted aspects of NOSI, Charlie changed his views on all aspects except for models and modeling during the program. He ended up the program as he started. The most significant changes Charlie made during the course itself were in the questioning and data/evidence aspects of NOSI (See Table 4). He also used those aspects on his CoRe and teaching practicum. On his exit interview, he explained what NOSI means to him:

> "It (science) all starts with a question, having that question develop into some sort of investigation to find answers. And then, if you go from there, there's multiple ways to do science. There's more than one way to get at your question. And then, you have to talk about your data and your evidence. This is what's supporting your claim at the end."

Rose ended the course with very informed views of tentativeness, subjectivity, creativity, theories/laws, and socio/cultural values of science (See Table 3). On her exit interview, Rose explained what NOS means to her:

> "There are the terms and the concepts within science that take science and apply it to the real world. Like with science being tentative or subjective or you know the data and the evidence and all of those. You're conducting experiments via collecting data, observations, and inferences. Again, I might mix up nature of science and nature of science inquiry. But they're a way to apply it to the student's prior knowledge or the fact that everything

is always changing and gathering different pieces of data and analyzing it."

As shown in her post concept map, CoRe survey, and her teaching practicum in Chapter IV, Rose had very informed understanding about successfully integrating NOS and NOSI aspects into her teaching, and finding a connection between those aspects.

Related to the development of Rose's understanding of NOSI, she changed her beliefs about every aspect of NOSI except models and modeling in science (See table 4). Of interest was the fact that Rose was aware that there are multiple ways to do science, however, throughout the program she was unable to change her views of this NOSI aspect.

Research Question 2

The focus of the second research question was to identify Rose and Charlie's understandings of pedagogical content knowledge (PCK) for NOS and NOSI. As explained in the earlier Chapters, PCK is a combination of content and pedagogical knowledge that is unique to teachers (Shulman, 1987). In order to understand Rose and Charlie's PKC based on the Magnusson PCK model (1999), the CoRe survey (Loughran et al., 2004; 2006), a pedagogical discontentment survey (Southerland et al., 2012), and follow-up interviews as primary data sources were implemented and analyzed for each participant. For the pre CoRe surveys, Charlie's three big NOS ideas were tentativeness, subjectivity, and multiple scientific methods. He added two more ideas, questioning and scientific models, on his post CoRe survey. Meanwhile, Rose's three big NOS ideas, were observation/inferences, data/evidence, and justification on her pre CoRe survey. she added two more big ideas, multiple scientific methods and subjectivity, on her post CoRe survey.

At the beginning of the program, Rose had more explicit ideas for teaching NOS and NOSI than Charlie. She had a clear plan and organization to teach specific NOS and NOSI aspects. She was aware of different teaching strategies and assessment techniques, and how to use those while teaching NOS and NOSI. On the other hand, Charlie had very general ideas and views of teaching science. However, by the end of the program, both Rose and Charlie's understanding of PCK changed significantly.

Related to their knowledge of orientation towards teaching science, Charlie and Rose preferred to use various teaching orientations to teach NOS and NOSI aspects. They both specifically pointed out the importance of inquiry based learning and changing students' understanding conceptually. They both believed that NOS and NOSI aspects are taught best throughout "activity driven" and "inquiry based" orientations. Rose wanted to know what her students already know about those aspects, and engage them to explore those aspects with mostly student cantered activities. On the other hand, Charlie's pre and post pedagogical discontentment survey showed that he believed that using inquiry based teaching across all content areas was very effective in teaching science.

There was not enough evidence to understand Charlie's knowledge of science curriculum based on the NOS and NOSI aspects he used in his CoRe survey. He never touched on science curriculum, or national/state standards. However, it cannot be said he had insufficient knowledge of it, either. When asked why he chose those particular big ideas, he was mostly aware of the importance of science contents and related curriculum. On the other hand, Rose was very comfortable about what and why it is important to teach the ideas of NOS and NOSI. Although she struggled with the idea of national and state standards, which limit teachers on how to teach NOS and NOSI, she felt very comfortable integrating nature of science throughout the curriculum.

Related to knowledge of student understanding in science, Charlie believed that age, student misconceptions, and content itself (very abstract or hard to learn concepts) are very important in successful teaching or learning of science concepts. Also, he thought that it was necessary for students to have enough conceptual ability and skills to fully understand any science concept. Meanwhile, Rose believed that teachers' knowledge about their students' understandings of science are one of the most influential factors for teaching science. She thought that if a teacher listened to students' ideas, and identified their prior knowledge and misconceptions, learning and teaching might be more effective and meaningful. Teachers can build on their teaching based on their students' understandings and needs for learning.

Another aspect of PCK is instructional strategies and representations in science. At the beginning of the program, Charlie did not have sufficient knowledge of this aspect. By the end, he was aware of different teaching strategies, and argued that different science contexts need different teaching strategies. He believed the most fruitful strategies to teach science were hands-on classroom activities, laboratory, and inquiry-oriented teaching. Meanwhile, Rose's knowledge of instructional strategies was not changed much. However, it can be said that Rose already had very informed views about different teaching strategies, especially teaching NOS or NOSI aspects. She believed that NOS/NOSI is learned best by doing, designing your own experiences, reviewing, repeating, and practicing. She highly recommended hands-on lab activities for meaningful learning. She also pointed to the importance of models, analogies, and illustrations to teach NOS and NOSI aspects.

Related to knowledge of assessment in science, Charlie maintained his initial views throughout the program. He talked about exit slips, classroom discussion, and question/answer session as being the primary ways of assessing student understanding. Although Charlie felt comfortable using traditional assessment techniques, he did not talk about those techniques or how they might be used as an assessment of students' understanding or confusion. On the other hand, Rose started the program with very informed knowledge about assessment in science, but she also ended with the same informed view. She clearly explained how different assessment techniques (Formative and Summative assessments) could be used in the different situations. She pointed to the importance of formative assessment such as classroom discussions, reflections, writing prompts, exit slips, or watching student work in a science classroom. Both Rose and Charlie mentioned more general connections to science, not related specifically to teaching of NOS and NOSI.

Research Question 3

The focus of the third research question is to understand what factors mediate preservice teachers' abilities and teaching experiences to enact their PCK for NOS and NOSI. Rose and Charlie successfully integrated the components of their pedagogical content knowledge (e.g., knowledge of representations and instructional strategies, knowledge of students' understanding of science, knowledge of assessments, and knowledge of curriculum) to create learning opportunities for their students. They relied upon their knowledge of subject matter, representations, instructional strategies, assessment, and curriculum to create opportunities, which may engage students in making and testing predictions as well as supporting claims and conclusions with evidence. Over and above, some additional factors such as, teacher self-efficacy, lesson planning, or general pedagogical knowledge had quite a few impacts on their teaching practicum.

Every single factor, which was identified in the results of research question three in Chapter IV for influencing participant teachers' teaching NOS and NOSI, has a relationship with each other, and any one cannot be considered alone. As Charlie and Rose pointed out many times, lesson planning sessions were very important for teaching NOS and NOSI because they had to think about each individual detail that might have a possible impact on the lesson. Thus, Rose and Charlie transferred their PCK and knowledge of other factors into the their own lesson plans. They taught some aspects of NOS and NOSI within the context the topic of "chemical reactions," so they needed to have sufficient content knowledge of both NOS/NOSI and that particular chemistry topic. They had informed content knowledge related to NOS and NOSI, as explained on the first research question. Their content knowledge of chemical reaction topic was not measured, but during the lesson, it was seen and observed that they had sufficiently enough content knowledge to teach it. On their lesson plan, it was seen that they had an adequate knowledge of science curriculum, and to both national and state standards related to NOS/NOSI and "chemical reactions." For each day of teaching, they clearly expressed their "content learning outcomes," "NOS/NOS learning goals," and "science practice outcomes".

Related to Rose and Charlie's knowledge of orientation towards teaching NOS and NOSI, as a general perspective, Rose and Charlie indigenized "inquiry-based" and "activity driven" orientations to teach both chemical reaction topics and NOSI/NOSI aspects. By analyzing their teaching practicum, it was seen that their orientation towards teaching science was affected by other factors, such as general pedagogical knowledge (i.e. classroom organization), different groups of students, and the topic itself. During the two-week teaching practicum, Rose and Charlie were able to successfully implement their teaching as they planned. However, they had some struggles with the students on the second week. Thus, they had to change their approach and re-oriented by using "didactic" teaching and "lecturing." Therefore, having a different group of student may influence their orientation towards teaching science. Other factors, such as instructional strategies or self-efficacy also may contribute. For example, when Rose and Charlie tried use "discovery" and "guided inquiry" orientations, some organization and teaching problems occurred during one lab activity.

Another important factor was Rose and Charlie's knowledge of students' understanding of science, which included knowledge of students' conceptions of particular topics, learning difficulties, misconceptions, motivation, diversity in ability, learning style, interest, developmental level, and need. Rose and Charlie mostly pointed out that teachers must have sufficient knowledge about what students know about a topic and areas of likely difficulty. Thus, they always started the lesson with eliciting their students' existing knowledge and their common misconceptions. Some days, they changed the lesson after considering their students' learning difficulties, motivations, and individual differences. Rose and Charlie's knowledge of students' understanding of science is related to their knowledge of instructional strategies and their assessment techniques. They developed their lesson in the light of inquiry-based teaching via conceptual change strategies. On each specific topic, they used representations, activities, examples, models, and investigations to build up their lessons. For example, to teach "subjectivity" and "observation/inferences," Rose and Charlie used various instructional strategies such as investigations, activities, giving examples, and connecting their prior knowledge to the lesson. Assessment was another aspect of PCK, which influenced teaching. In fact, Rose and Charlie defined it as two separate categories: formative assessment and summative assessment. They used many formative assessment techniques in their lesson such as discussions, working on models, drawings, and presenting lab reports.

Another influencing factor was teachers' self-efficacy towards teaching NOS/NOSI as well as teaching any subject matter. Rose had higher levels of efficacy and was more likely to learn and use innovative strategies for teaching, implement management techniques that provided for student autonomy, set attainable goals, persist in the face of student failure, willingly offer special assistance to low achieving students, and design instruction that developed students' self-perceptions of their laboratory and activity skills. Thus, Rose was an organizer and dominated the lesson and she believed she was capable of problem solving during teaching.

In addition, the entire 13-month program, including research and the methods course, greatly impacted Rose and Charlie's views on NOSI and NOSI, as well as their pedagogical content knowledge of teaching NOS/NOSI aspects. Rose and Charlie pointed out that practicing, lesson planning, and discussions after teaching were all very important and had an impact of their teaching effectiveness.

In the end, Rose and Charlie successfully taught targeted aspects of NOS/NOSI by integrating them into the topic of "chemical reactions." They successfully transferred their NOS/NOSI subject matter knowledge, and PCK for NOS/NOSI into their teaching practicum. In addition to all of the previous factors already discussed which influenced their teaching, Rose and Charlie also believed that practicing and having a chance to use their knowledge via teaching were the most important factors for successful and effective teaching of NOS/NOSI. Charlie and Rose explained what "effective teaching" means for them:

> Charlie: "I think effective science teaching is any way that you can impart your knowledge into your students. And that they retain that knowledge, so whether it has to be through some sort of lecture or some sort of investigation or experimentation, as long as they can connect the information. Or retain the information to use in the future. Then, you're an effective science teacher. (Charlie Exit Interview)
>
> Rose: "I'd say effective science teaching is getting your students not only to understand you know what they're doing, but being able to apply it to the real world, hopefully being excited about it. I don't think students are going to be excited about science because not all of them are interested. But getting them to be excited, getting them to be interested, getting them to ask questions. I think that asking questions is very effective because they're not just doing what you they think you want them to. They're not

> just giving a question an answer. But if they're asking questions, their mind is working and they're curious and they're wondering; they're going to want to explore more. So, I mean effective science is teaching is not only reaching the objectives, but getting the students interested and engaged in what they're doing and really experiencing what they're learning because then I think they're more apt to take it with them in the future. And there are going to be more apt to ask questions and want to learn more about it." (Rose Exit Interview)

Discussion

The purpose of this section is to compare the findings of the study to the existing literature base and to highlight how this study contributes to the literature. The literature review revealed a significant gap in the literature examining the practice and pedagogical content knowledge held by preservice teachers for teaching nature of science and nature of scientific inquiry. In the following section, the similarities and differences between the reviewed literature and the research findings of the study are discussed.

The purpose of this study was to examine how preservice science teachers' understanding of NOS/NOSI and pedagogical knowledge have changed over the program, and manifests itself in their classroom practice. Related to the first research question, given the large body of research over the past decades that examined preservice science teachers' views of NOS and NOSI, it was expected that the participants in this study would hold a number of misconceptions, which have been referred to elsewhere as "naive" or "inadequate" views (Lederman, 1992; 2007). Unlike the existing literature, Rose and Charlie initially had "mixed" or "informed" views of NOS and NOSI at the beginning of the program. They struggled with only three aspects of NOS/NOSI, which were “tentativeness,” “scientific theories and laws,” and “socio-cultural value.” The explicit/reflective approach of teaching Rose and Charlie NOS and NOSI in this setting, favorably changed their understandings of the target NOS and NOSI aspects. Explicit/reflective instruction involves purposeful teaching of NOS through expected learning outcomes, drawing students’ attention to NOS aspects in connection to other learning experiences, prompting students to reflect upon their experiences in light of NOS aspects, and assessing students NOS conceptions in various contexts. However, many such efforts to improve pre-service teachers’ conceptions of NOS have met with limited success in helping develop teachers’ views of NOS that are consistent with current reforms (Akerson & Hanuscin, 2003). Studies show that some preservice teachers still struggle with understanding some aspects of NOS even when explicit/reflective NOS instruction is given (Abd-El Khalick & Akerson 2004; Lederman 2007).

Specifically, it is argued that the explicit/reflective interventions employed in this context contributed to these changes by providing opportunities for Rose and Charlie to (1) clarify the scientific meaning of the terms NOS/NOSI, and (2) construct a coherent framework of NOS/NOSI by relating the various aspects to each other. By providing these opportunities, the explicit/reflective instruction addressed different types of NOS and NOSI misconceptions, such as scientific knowledge is unchanging, or there is only one scientific method and every scientist need to follow it.

As explained in the literature review section, some aspects of NOS and NOSI are more easily altered than others even with explicit/reflective NOS/NOSI instruction (Mesci & Schwartz, 2016). However, Rose and Charlie made positive progress even in the aspects, which are often difficult to change, such as "scientific theory and law." Rose and Charlie's background knowledge and a course taken by Rose and Charlie, had an impact on their success in improving their understanding of most aspects of NOS and NOSI.

> "I learned most of those stuff in Bio 2700 (taught by the same instructor) lesson last year. After I took this course, I did talk about inquiry during my method's course. So I thought about inquiry in general. But I just think that; I think it's part of the way that I learn, especially with like my world views. Like I feel very strongly about experiencing science and practicing it." (Rose Exit Interview)

The results related to second and third research question were presented based on the PCK model of Magnusson et al. (1999) and by analyzing Rose and Charlie's responses on the CoRe survey (Loughran et al., 2004; 2006), which provided an overview of how participants conceptualize the content of particular subject matter. The results showed that Rose and Charlie changed their understanding on some of the PCK elements like "knowledge of instructional strategies," and "knowledge of assessment in science." On the other hand, some elements of PCK such as "knowledge of science curriculum" were more difficult to ascribe any change in beliefs of each participant over the time.

As reviewed in Chapter II, Magnusson et al. (1999) conceptualized PCK as being composed of five components: (1) orientations toward teaching science (teachers' knowledge and beliefs about the purposes and goals for teaching science at a particular grade level); (2) knowledge of science curriculum (knowledge of the goals and objectives for students in the subject and of programs and materials relevant to teaching the specific subject); (3) knowledge of students' understanding of science (knowledge of requirements for learning and knowledge of areas of students' difficulty); (4) knowledge of instructional strategies (knowledge of subject-specific and topic-specific strategies), and (5) knowledge of assessment in science (knowledge of the dimensions of science learning that are important to assess and the methods by which that learning can be assessed). As mentioned in this model, Magnusson et al. (1999) argued teachers' orientations toward teaching science shapes and is shaped by the other four components. As the components may interact in very complex ways, teachers need to develop knowledge of all aspects of PCK (Magnusson et al., 1999). In this sense, PCK is the result of a transformation of knowledge from other domains. The model of PCK representation developed by Magnusson et al. (1999) has been used by a number of researchers as they try to capture PCK (e.g. Berry, Loughran, & Van Driel, 2008; De Jong, Van Driel, & Verloop, 2005; Nilsson, 2010) and is also used in this dissertation as a way to capture two preservice science teachers' development of PCK for NOS and NOSI.

Rose and Charlie's orientations towards teaching science were driven by their knowledge about students in learning and how students learn most effectively. The results are consistent with studies by Park and Oliver (2007) and David and Smithy (2009) who found teachers' core beliefs about learning and teaching informed the implementation of inquiry-based instructional strategies. Thus, Rose and Charlie's knowledge of orientation towards teaching science might inform instructional decisions made during planning and teaching. As Magnusson et al. (1999) identified, PCK includes an integration of subject matter knowledge with knowledge of instructional strategies and representations. The results of this study support the findings of Van Driel et al. (1998), which identified that using analogies and models indicates an integration of teachers' knowledge of subject matter with their knowledge of representations, instructional strategies, and students as science learners. Another important component of PCK is knowledge of students' understanding of science. Rose and Charlie believed that prior knowledge of students is an important factor in students' learning. For example, when their students were asked to make an inference from an activity, they had a difficulty because their prior knowledge restrained their inferences. Many studies have supported Rose and Charlie's belief about the influence of prior knowledge upon student learning (Gess-Newsome and Lederman, 1999; Kind, 2009). PCK literature emphasizes the importance of revealing students' prior knowledge to address students' misconceptions prior to instruction.

Rose and Charlie also held informed knowledge of assessment in terms of facilitating students' learning. They recognized and pointed out the importance of formative assessment to pre-assess students' prior knowledge and elicit misconceptions. Earlier studies have reported two categories of formative assessments including: (a) planned formative assessments and (b) informal formative assessments (Loughran et al., 2008). In this study, Rose and Charlie used students' predictions as informal formative assessments prior to investigations to gain insight into students' prior knowledge and identify misconceptions. However, Rose and Charlie did not have any particular idea or plan for teaching specifically NOS and NOSI. Their understandings and efforts were mostly about general science teaching. Related to Rose and Charlie's knowledge of science curriculum, they noted the content of eighth grade NOS and NOSI are determined by state and national standards. Avery and Carlsen (2001) indicated that teachers adapted the curriculum to address curricular mandates and include instructional models to support students' learning. This study supported the results of Avery and Carlsen (2001).

The findings of this study confirmed the results of Hume and Berry (2011), which indicated that working with CoRe in a planned and strategic approach in student teacher chemistry education is very important and effective for improving their awareness of PCK components (Magnusson et al. 1999), and building their knowledge of those components for given topics and groups of students. The results of this current study showed that as a tool for developing PCK components, the design of a CoRe is a difficult task for preservice teachers. However, if the CoRe is carefully completed, it could enable preservice teachers to begin thinking about and developing their lessons by considering PCK components. Because of Rose and Charlie's lack of classroom experience at this stage, it is a limiting factor in their PCK development but the findings from this current study showed that completing the CoRe survey might be a good start for such growth and development.

Bell, Lederman, and Abd-El-Khalick (2000) looked at teachers' translation of knowledge into instructional planning and classroom practice. Although all of the preservice teachers exhibited adequate understandings of NOS, they did not consistently integrate NOS into instruction in an explicit manner. NOS was not evident in these teachers' objectives, nor was any attempt made to assess students' understandings of NOS. The authors concluded that possessing an understanding of NOS is not automatically translated into a teacher's classroom practice. They further concluded that NOS must be planned for and included in instructional objectives, like any other subject matter content. The results showed that the depth of NOS understanding, subject matter knowledge, and the perceived relationship between NOS and science subject matter affected the teachers' learning and teaching of NOS. The teacher with more extensive subject matter background, who also held a better developed understanding of NOS, was better able to address NOS throughout his teaching. This teacher's extensive subject matter background enabled him to address NOS throughout his teaching regardless of science topic. The teacher with less extensive subject matter knowledge was limited with respect to where she could integrate NOS. In addition, this teacher seemed more wedded to the examples of NOS integration provided in her preservice education program. The results of this current study illustrated for the first time that knowledge of subject matter was a mediating factor in the successful teaching of NOS and NOSI.

Recent studies have pointed out teacher efficacy as an important factor of teachers' success and competence to teaching, which is more powerful than self-concept, self-esteem, and perceived control (Gess-Newsome & Lederman, 1999). Findings of this study supported those which reported that a higher sense of efficacy, both individually and as a school collective, tend to be more likely to enter the field, report higher overall satisfaction with their jobs, display greater effort and motivation, take on extra roles in their schools, and are more resilient across the span of their career (Park & Oliver, 2007). Teachers' self efficacy was not within the original framework of this current study, but we have a linked success in teaching NOS and NOSI to efficacy through emergent codes, and feel that it plays a critical role in defining problems and determining teaching strategies to solve the problems, therefore leading to the reorganization of knowledge. Taken together, it might be reasonable to view teacher efficacy as an external component of teachers' knowledge.

Over all the literature in science education addresses the importance of an integrated knowledge of teachers into science teaching on all content areas. Verlopp et al. (2001) investigated experienced teachers' knowledge and beliefs of teaching practice, formal teacher preparation, and professional development. Nilsson and Loughran (2012) argued that the PCK of preservice teachers is an integration of subject matter knowledge and their knowledge of student understanding of science. Nilsson and Loughran (2012) and Verloop et al.'s (2001) descriptions of integrated teacher knowledge were supported by the results of this study, which show that Rose and Charlie reported varying their representation and instruction to address different groups of students and individual differences. Rose and Charlie were observed teaching the NOS and NOSI concepts, which made the integration of the components of their PCK. Thus, Rose and Charlie successfully used their knowledge for teaching NOS and NOSI aspects to include subject matter knowledge, knowledge of student difficulties, misconceptions, representations, instructional strategies, and assessment to engage and activate students and support their construction of a conceptual framework for NOS and NOSI.

As the framework of this study, Magnusson et al.'s (1999) PCK model describes the components of PCK as separate entities only interacting with teacher orientation and not informing one another. After the results of this study, a new model (see Figure 19) representing a more integrated PCK for teaching NOS and NOSI is developed along with new components. On this topic-specific PCK model, the five components of the Magnusson et al. (1999) PCK model and emergent external components such as, teacher self-efficacy, have a strong relationship to one another. Teaching NOS and NOSI aspects are integrated into the nature of teacher knowledge of PCK components. Learning difficulties, topic-specific representations, instructional strategies, assessments, and curriculum are included within each PCK component. Each PCK component is embedded within lesson planning and instruction. Developing lesson plans and teachers' PCK for NOS/NOSI have a potential influence one another. Therefore, the relationship between lesson planning, teachers' PCK for NOS/NOSI and teaching practicum is shown with double arrows in our purposed model.

Subject matter knowledge of NOS/NOSI, teacher self-efficacy, and general pedagogical knowledge are also shown as external influences, and they may directly have an impact on teachers' effective NOS and NOSI teaching. Thus, this model might represent teachers' PCK for teaching NOS and NOSI.

Implications

In this section, implications for preservice science teacher program, science teachers' classroom practice, and future researchers are identified.

For Preservice Science Teacher Program

As Gess-Newsome and Lederman (1999) emphasized on the necessity of making sure that teachers consider their subject matter for teaching during their preparation, professional development programs must place explicit import on these structures by giving preservice teacher enough time to reflect in order to include more integrated and connected aspects of NOSI and NOSI in their teaching practice. This appears particularly important regarding how the connections of NOS and NOSI and thematic elements might be specifically included in classroom practice and intertwine with traditional subject matter.

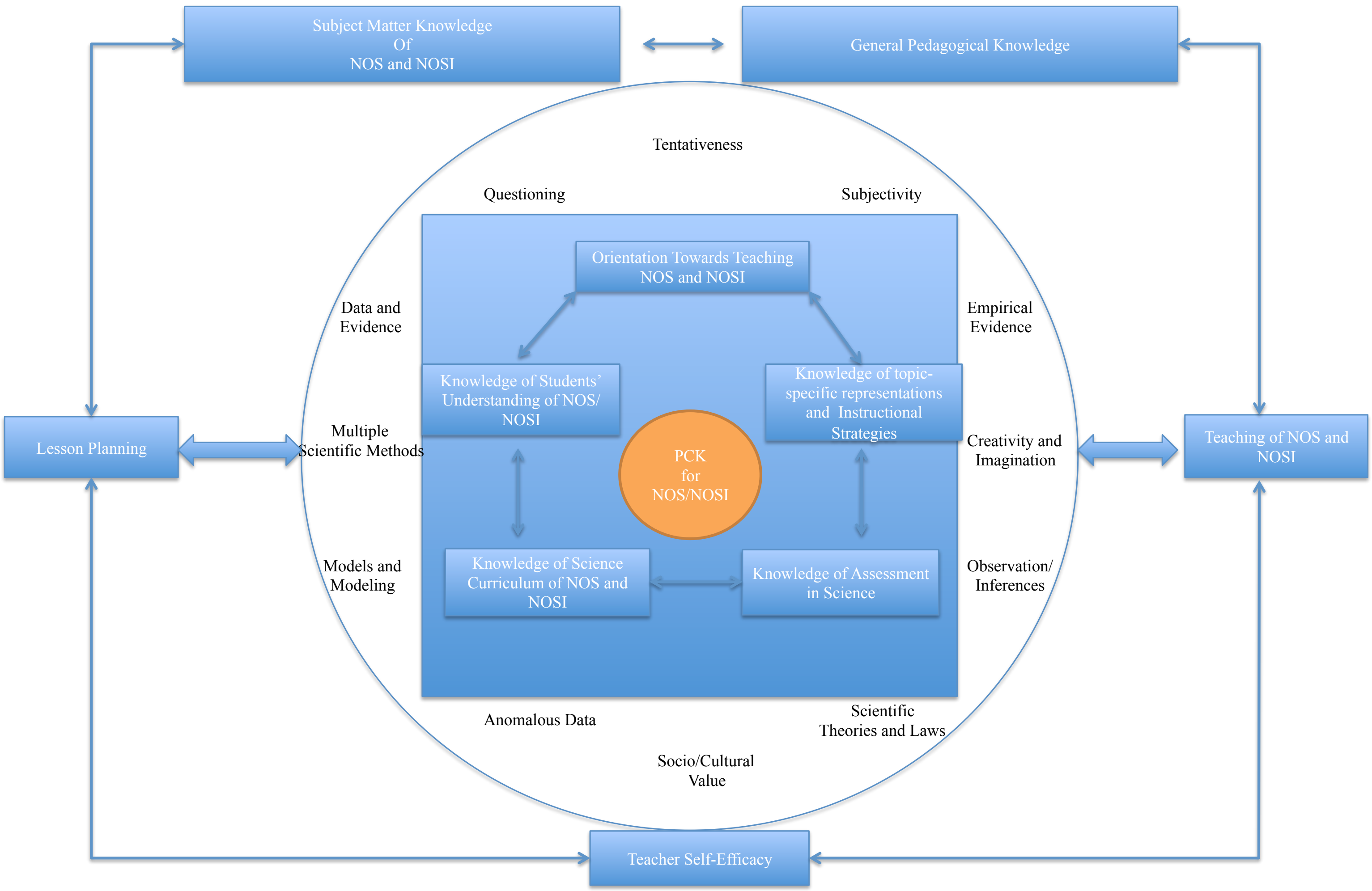

Figure 19. Purposed Model of PCK for Teaching NOS/NOSI

Teacher preparation and development programs need to prepare teachers with significant model lessons, and planning for the inclusion of NOS and NOSI in their current curriculum. Also, teaching NOS and NOSI must be supported in teachers' efforts to integrate the model curriculum of targeted NOS and NOSI aspects into the classroom. This effort must be focused on making the connections between NOS and NOSI aspects explicit, and for potential overarching conceptions.

In addition, it is important to recognize that NOS and NOSI must be integrated into subject matter that teachers are required to teach. However, the current standards do not do an adequate job of integrating NOS and NOSI concepts into science curriculum at the K-12 level. This lack of integrated standards in the curriculum provides teachers with little support from their formal science classrooms, or related professional teacher development. This is specifically concerning given the ability of teachers to continue to work up and develop their PCK regarding NOS and NOSI, and maintain a required emphasis on its implication into teaching practice.

It would appear that using the CoRe and follow-up interviews might be an effective way to help teachers' improves their PCK. The application of the CoRe prior to, during, and at the end of explicit teaching of NOS and NOSI, might help to put emphasis on potential connections between targeted aspects and NOS and NOSI. The CoRe also may potentially have to enable teachers to have a more durable conception of NOS and NOSI. Moreover, this type of development in relation to explicit attention to learners' PCK for NOS and NOSI, may serve to facilitate the translation of this knowledge into their teaching practicum. Also, by using a CoRe methodology, science teacher educators may propose preservice teachers alternative ways of planning, implementing, performing, and evaluating their lessons with regard to their learning about teaching needs and difficulties. As this current study showed, preservice teachers' PCK for NOS and NOSI offers a lens for exploration learning about becoming a science teacher that might be used in meaningful ways in teacher preparation programs.

For Classroom Practice

Implementing the CoRe or similar surveys would, in the light of findings of the current study and the numerous research that has used similar methodologies (Bertram & Loughran, 2012; Gess-Newsome & Lederman, 1999; Nilsson & Loughran, 2011; Park & Oliver, 2007), create clear implications for teachers' classroom practice, both as an instructionally effective tool to facilitate development, but also as a means for assessing students' understandings of NOS and NOSI along with using VNOS and VOSI questionnaires. The impact of these surveys, in utilization of teachers' PCK for NOS and NOSI into their classroom practice might have a power of providing teachers with a substantial reference to guide their own performance at planning, implementing, and assessing their classroom practice with related to their specific conceptions of NOS and NOSI.

Moreover, the use of these methodologies for understanding students' conceptions of NOS and NOSI, and even how those conceptions might interact with traditional subject matter, would also be a useful attempt, in light of the findings of this current study. The results of the CoRe clearly provided insight into which concepts of PCK are the most prominent for a preservice teacher. It has a potential use in formative assessment in value for classroom practice. In related to the VNOS and VOSI surveys, the CoRe would provide worthwhile insight into preservice teachers' conceptions of NOS and

NOSI, and might be used to inform adaptations to classroom practicum, potentially regarding to their PCK for any subject matter.

The relation of preservice teachers' PCK for NOS and NOSI may be an increasing concern with the recent version of the Next Generation Science Standards (Achieve, Inc., 2013; NGSS). NGSS includes the integrated conceptions of "scientific knowledge", "the practice of scientific and engineers", and "other essential interwoven concepts". In regarding with understanding of NOS and NOSI are not as explicit and clear in the NGSS. It should be a necessity for successful implementation because classroom teachers apparently have a challenge to integrate curriculum regarding to NOS and NOSI into teaching practicum.

Science Education Research

The results of this dissertation confirmed many researchers' competition about meaningful connections between aspects of NOS and NOSI. In this case, concept map or a similar methodology might be a very effective tool for assessing those connections or cross-linking between aspects of NOS and NOSI. Instead of arguing separating NOS and NOSI, or extending aspects of those concepts, science education researchers should focus on the alternative and effective ways of making learners to find meaningful connections and understand those conceptions.

In regarding to teachers' PCK for NOS and NOSI, Park and Oliver (2008) noted that ''it has been difficult to portray a clear picture not only of how to scaffold PCK development in teachers but also of how to assess it once constructed'' (p. 262). Thus, in science teacher education, it might be suggested that paying more careful attention to the components of PCK, and how these are developed and personally assessed (e.g., CoRe or an alternative instrument). The findings of this study clearly represented that there is a potential for focusing on developing preservice teachers' PCK in ways that can make a construction to their professional learning process. The results of this study indicated that the employing of a tool such as a CoRe encourages preservice teachers to begin embracing the notion of PCK in their own practice, as a trigger impact.

In order to learn through experiencing for minimizing the discomfort of being less certain about what is happening on the classroom, preservice teachers need an opportunity to take some risks. However, they might feel the necessity to look for safety in their teaching. In order to that, preservice teachers should begin to lay hold of and better understand the complexity of science teaching and learning. Thus and so, the goal of science teacher education is not to explain student teachers how to teach, but to guide them to find reasons about their teaching as well as to help them make explicit their needs difficulties, and concerns for teaching (Nilsson 2008).

The findings of the current study indicate that the CoRe does appear to provide a more accurate sign of what and how aspects of NOS and NOSI are going to present in teachers' classroom practice. In attempt to generate more complete profile of respondents' PCK for NOS and NOSI, and to potentially facilitate reflection on their teaching practices, future research could investigate the effectiveness of proposed model of PCK for NOS and NOSI (see Figure 5) and should give a chance teachers to teach other aspects of NOS and NOSI, which were not chosen by Rose and Charlie on their teaching practicum.

This current study represented two successful preservice teachers' PCK for NOS and NOSI, and their successful teaching practicum. Both Rose and Charlie had improved their understanding of NOS and NOSI aspects and their PCK for NOS and NOSI. Future research could investigate unsuccessful cases, both development level during the whole program regarding to PCK for NOS and NOSI, and translating those knowledge into their teaching in order to represent the potential reasons of this failure of the preservice teachers who participated the same or similar teacher development program. Also, it needs to be investigated the preservice teachers who had not showed any improvements on their subject matter knowledge of NOS and NOSI, but they did a successful teaching of NOS and NOSI.

Also, it was not possible to assess the 8th grades understanding of the targeted NOS and NOSI aspects, which may have allowed for a greater understanding of the quality of teaching by Rose and Charlie. It was very hard to assess their understanding because of the consent difficulties and time limitation of preservice teachers' teaching sessions in this current study. Thus, this factor might be included in the future research in order to assess teachers' science teaching effectiveness.

Limitations

The number of participants might be a limitation of this current study. It could be considerably informative to analyze the whole group of preservice teachers who participated in the 13-month program. However, this case study, using detailed qualitative data point was best suited to investigate a small number of preservice teachers' PKC for NOS and NOSI and the translation of those into the teaching practicum.

The conceptions of NOS and NOSI guiding the current investigation also served to potentially limit the generalizability of the findings at this point. While considerable research has been likewise guided by the seven aspects of NOS and five aspects of NOSI, it is unclear whether other conceptions of NOS and NOSI could include a different assortment of targeted aspects. Also, this issue could potentially impact the translation of these conceptions into classroom practice. Expanding the focus of an investigation similar to the current one to include a qualitative analysis of other included aspects of NOS and NOSI may provide a more complete measure of the degree to which teachers' conceptions of NOS and NOSI are evidenced in their practice.

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APPENDICES

Appendix

A. Views of Nature of Science (VNOS-270) Questionnaire

VNOS-270

Name: ________________________________

Date: ________________________________

- Please answer each of the following questions. You can use all the space provided to answer a question.
- Some questions have more than one part. Please make sure you write your answers to each part in the appropriate space provided.
- This assignment will not be graded. There are no "right" or "wrong" answers to the following questions. I am only interested in your ideas relating to the following questions.

1. What, in your view, *is* **science**? How can you determine when something **is** science (such as biology or physics) and when something is **not** science (such as religion or philosophy)?
2. How are science and art similar? How are they different?
3. Scientists agree that about 65 millions of years ago the dinosaurs became extinct. However, scientists still disagree about what caused this extinction.
    a. Why do you think they disagree even though they all have the <u>same</u> information?
    b. Do you think this controversy could be resolved? If so, how? If not, why not?
    c. How do you think scientists know how dinosaurs looked and moved?

4. There are many types of phenomena (past, present, and future) that scientists study, but cannot see. For example, scientists have never seen "dark matter", the center of the earth, or into the nucleus of an atom. Yet many scientists use their understanding of these phenomena to do research.
   a. If they have never seen these things, what kind of information do scientists use to figure out these things exist or what they look like?
   b. Should we, as a public, accept scientists' explanations or descriptions of things they have not seen? Why or why not?
5. Scientists try to find answers to their questions by doing investigations. Do you think that scientists use their imagination & creativity in their investigations?
   a. If you think "YES", explain why and in what part of their investigations (planning, analysis of data, interpretation, etc.) you think they use their imagination & creativity
   b. If you think "NO", explain why imagination & creativity are not part of science.

6. What do you think is the difference between a scientific theory and a scientific law?
   a. A scientific theory is….
   b. A scientific law is….

Give an example of a scientific theory and an example of a scientific law.

Example of a Scientific Theory:

Example of a Scientific Law:

   c. Do you think scientific theories we have today will change in the future? Why or why not?

d. Do you think scientific laws we have today will change in the future? Why or why not?

7. Some claim that science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that science is universal. That is, science transcends national and cultural boundaries and is not affected by social, political, and philosophical values, and intellectual norms of the culture in which it is practiced.

a. If you believe that science reflects social and cultural values, explain why. Defend your answer with examples.

b. If you believe that science is universal, explain why. Defend your answer with examples.

Appendix

B. Views of Nature of Scientific Inquiry (VOSI- 270)

VOSI-270

Name________________________________ Date______________________

- Some questions have more than one part. Please make sure you write your answers to each part in the appropriate space provided.
- This assignment will not be graded. There are no “right” or “wrong” answers to the following questions. I am only interested in your ideas relating to the following questions.

1. What types of activities do scientists (e.g., biologists, chemists, physicists, earth scientists) do to learn about the natural world? Discuss how scientists (biologists, chemists, earth scientists) do their work.
2. A lot of science relies on terminology. We’d like to know how you understand and use some of common terms in science.
    a. What do you think a scientific experiment is? Give an example to support your answer.
    b. Does the development of scientific knowledge require experiments?

       <u>If yes</u>, explain why. Give an example to defend your position.

       <u>If no</u>, explain why. Give an example to defend your position.
    c. What does the word “data” mean in science?
    d. Is “data” the same or different from “evidence” ? Explain.
3. Models are widely used in science. What is a scientific model? Describe and give an example.

A scientific model is….

Give example of model….

4. A person interested in animals looked at hundreds of different types of animals who eat either meat or plants. He noticed that those animals who eat similar types of food tend to have similar teeth structures. For example, he noticed that meat eaters, such as lions and coyotes, tend to have teeth that are sharp and jagged. They have large canines and large, sharp molars. He also noticed that plant eaters, such as deer and horses, have smaller or no canines and broad, lumpy molars. He concluded that there is a relationship between teeth structure and food source in the animals.
   a. Do you consider this person's investigation to be an **experiment**? Please explain why or why not.
   b. Do you consider this person's investigation to be **scientific**? Please explain why or why not by describing what it means to do something "scientifically."

This investigation **is** / **is not** (circle one) scientific because………………

5. The "scientific method" is often described as involving the steps of making a hypothesis, identifying variables (dependent/independent), designing an experiment, collecting data, reporting results. Do you agree that to do good science, scientists must follow the scientific method?

_______YES, scientists must follow the scientific method

_______NO, there are many scientific methods

- If YES (you think all scientific investigations must follow a standard set of steps or method), describe why scientists must follow this method.

- If NO (you think there are multiple scientific methods), explain how the methods differ and how they can still be considered scientific.

6. Scientists do lots of investigations and then share their findings with other people. They publish their work in scientific journals. They speak about their work at meetings and even on TV.
    a. How do scientists know when they are ready to make their research results public?
    b. What kind of information do they need in order to convince others that their findings are valid (believable)?
7. Scientists sometimes encounter inconsistent findings (*anomalous* information).
    a. How are anomalies identified in science? (i.e. What is considered "inconsistent" in scientific research?) Provide an example, if possible.
    b. What do you think scientists do when they find an anomaly?
    c. Do you think all scientists identify and handle anomalous information this same way? Why or why not?
    d. How do students typically identify and handle anomalies (inconsistent data) in a science classroom? What do you think is the motivation for students to do this?
    e. Do you think students and scientists handle anomalies in the same way?

Appendix

C. Nature of Science and Nature of Scientific Inquiry Continuum Scale

NOS Continuum Scale

Tentativeness	-	(+)	+	++	+++
Creativity	-	(+)	+	++	+++
Subjectivity	-	(+)	+	++	+++
Observation/inference	-	(+)	+	++	+++
Empirical	-	(+)	+	++	+++
Theory/law	-	(+)	+	++	+++
Socio/Cultural	-	(+)	+	++	+++

Experiment	models	justification	data/evidence
General	physical	evidence	same
Controlled	exact replica	“proof”	different:
Required	explanation	data	
Other:	process	reproducible	
	Prediction	others repeated	
	Test	other:	
	visual		

NOSI Continuum Scale

Questions	-	(+)	+	++	+++
Multiple Methods	-	(+)	+	++	+++
Multiple Purposes	-	(+)	+	++	+++
Justification	-	(+)	+	++	+++
Anomalies	-	(+)	+	++	+++
Data/Evidence	-	(+)	+	++	+++
Practice	-	(+)	+	++	+++

<u>Experiment</u>	<u>models</u>	<u>justification</u>	<u>data/evidence</u>
General	physical	evidence	same
Controlled	exact replica	“proof”	different:
Required	explanation	data	
Other:	process	reproducible	
	Prediction	others repeated	
	Test	other:	

Appendix

D. Illustrative Examples of Informed and Naïve Views for the NOS and NOSI

Illustrative Examples of Informed and Naïve Views for the NOS and NOSI

Aspects of NOS	More Naïve Views	More Informed Views
Tentativeness	"Compared to philosophy and Religion…Science demands definitive… right and wrong answers." "If you get the same results over and over and over, then you become sure that your theory is a proven law, a fact."	"Everything in science is subject to change with new evidence and interpretation of that evidence. We are never 100% sure about anything because… negative evidence will call a theory or law into question, and possibly cause a modification."
Subjectivity	"Scientists are very objective because they have a set of procedures they use to solve their problems. Artists are more subjective, putting themselves into their work."	"Scientists are human. They learn and think differently, just like all people do. They interpret the same data sets differently because of the way they learn and think, and because of their prior knowledge."
Observation/Inference	"Science would not exist without scientific procedure which is solely based on experiments . . . The development of knowledge can only be attained through precise experiments."	"Scientists take what data they have and drawn conclusions based on it and things like earthquakes and volcanoes. We will probably never know for sure, but we may be able to draw different conclusions based on different data."
Empirically Based	"Science is concerned with facts. We use observed facts to prove that theories are true."	"Much o f the development o f scientific knowledge depends on observation...[But] I think what we observe is a function o f convention. I don't believe that the goal of science is (or should be) the accumulation of observable facts. Rather science involves abstraction, one step of abstraction after another."
Creativity/Imagination	"A scientist only uses imagination in collecting data. But there is no creativity after data collection because the scientist has to be objective."	"Logic plays a large role in the scientific process, but imagination and creativity are essential for the formulation o f novel ideas...to explain why the results were observed."
Theory/Law	"Laws started as theories and eventually became laws after repeated and proven demonstration." "A scientific law is somewhat set in stone, proven to be true. A scientific theory is apt to change and be proven false at any time."	"A scientific law describes quantitative relationships between phenomena such as universal attraction between objects. Scientific theories are made of concepts that are in accordance with common observation or go beyond and propose new explanatory models for the world."

Aspects of NOSI	More Naïve Views	More Informed Views
Questioning	"I agree (that is does not start with a question), because scientists don't always need to have a question."	"Yes (it does start with a question), because in order to know what to investigate you have to have a question asking you or telling you what to find."
Multiple Scientific Method	"I think this should be done because it gives good data and good results. It is a good method to make sure that science is being done great."	"Scientists can follow different methods depending on what they want to answer. Sometimes they do experiments and sometimes they can only make observations. Both are science because they both are from the real world."
Data/Evidence	"They are the same because you collect both." "Evidence is the physical stuff, not numbers."	"Evidence comes from the data through analysis and supports a conclusion." "Data is information until it is interpreted, then it becomes evidence."
Scientific Models	"Scientists do not use models in science. They need observable and touchable data."	"A scientific model is a representation of a situation to give us the ability to view and manipulate and help with understanding."
Anomalous Data	"More tests are conducted to see why this happened. Some scientists may not include the anomaly because it doesn't go along with their results."	"You look to verify if the equipment is running properly or if you made a blunder in preparing the sample....You look for obvious mistakes...If you can't seem to account for this anomaly on that basis, then you have to begin to question the premise or hypothesis that is the premise behind the experiment...that nature is not behaving in accordance with whatever your expectations were..."

Appendix

E. Content Representation Survey (CoRe)

CoRe Survey

	Big Idea-1	Big Idea-2	How meaningful or important do I think this question is for me when I reflect on my teaching? Grade on a scale of 1 (low) -10 (high).	How confident do I feel when I respond to this question? Grade on a scale of 1 (low) -10 (high).
1.What do you intend the students to learn about this idea?				
2.Why it is important for students to know this?				
3.What else do you know about this idea (that you do not intend students to know yet)?				
4.What difficulties/ limitations are connected with teaching this idea?				
5.What is your knowledge about students' thinking which influences your teaching of this idea?				
6.What other factors influence your teaching?				
7.What teaching procedures will you use and what are the particular reasons for using these to engage with this idea?				
8.What specific ways do you have of ascertaining students' understanding or confusion?				

Appendix

F. Science Pedagogical Discontentment Survey

Science Teachers' Pedagogical Discontentment Survey (Revised)

Demographic Information

What is your gender? _____

What is the year of your birth? _____

Science Teaching (Dis)Contentment

We all have aspects of our teaching practice that we feel we do particularly well, that make us particularly effective as a teacher; we are content with these aspects of our teaching. On the other hand, there are often aspects of teaching that we feel that we are not particularly good at, that prevent us from being as effective as we can or should be; we are discontented with these aspects of our teaching. This questionnaire asks you to reflect upon your current science teaching and to think about the level of contentment and discontentment you hold about a number of science teaching practices. In this questionnaire we want you to consider if your performance of these practices *helps* you to reach your teaching goals? Too, we want you to consider if your performance of these practices *prevents* you from reaching your teaching goals. Through this instrument, we hope to gain some understanding of your personal state of contentment or discontentment with your science teaching.

Years of teaching experience?

Grade level(s) and subject(s) currently teaching?

I. General Job (Dis)Contentment
Before we focus on your teaching practices, it is important to note significant things about your teaching situation—the environment in which you practice. Are there things about your current teaching environment or situation with which you are experiencing discontentment—that prevent you from teaching effectively? If so, explain. (Can be continued on the back of this page.)

II. Specific Science Teaching Discontentment
Read each statement below and indicate your *level of discontentment* in terms of your own science teaching. In other words, how discontent are you *currently* with these aspects of your daily science teaching? Next to each item, **circle one** of the following choices:

1 = no discontentment
2 = slight discontentment
3 = moderate discontentment
4 = significant discontentment
5 = very high discontentment

1.	Ability to lead successful inquiry-based activities/learning	1	2	3	4	5
2.	Teaching science to students of lower ability levels	1	2	3	4	5
3.	Balancing personal science teaching goals with those of state and national standards	1	2	3	4	5
4.	Monitoring student understanding through alternative forms of assessment	1	2	3	4	5
5.	Orchestrating a balance between the needs of both high and low ability-level students	1	2	3	4	5
6.	Preparing students to assume new roles as learners within inquiry-based learning	1	2	3	4	5
7.	Using inquiry-based teaching within all content areas	1	2	3	4	5
8.	Assessing students' understandings from inquiry-based learning	1	2	3	4	5
9.	Assessing students' nature of science understandings	1	2	3	4	5
10.	Finding connections between science content and students' everyday lives	1	2	3	4	5
11.	Including all ability-levels during inquiry-based teaching and learning	1	2	3	4	5
12.	Teaching science to students from economically disadvantaged backgrounds	1	2	3	4	5
13.	Planning and using alternative methods of assessment	1	2	3	4	5

1 = no discontentment
2 = slight discontentment
3 = moderate discontentment
4 = significant discontentment
5 = very high discontentment

14.	Identifying students' prior science misconceptions	1	2	3	4	5
15.	Translating personal science knowledge to instructional levels appropriate for my students	1	2	3	4	5
16.	Having sufficient science content knowledge to generate lessons	1	2	3	4	5
17.	Teaching science to students of higher ability levels	1	2	3	4	5
18.	Teaching science subject matter that is unfamiliar to me	1	2	3	4	5
19.	Teaching science to students who previously have had less successful experiences in school science	1	2	3	4	5
20.	Integrating nature of science throughout the curriculum	1	2	3	4	5
21.	Adapting science teaching strategies to reach ability levels of all students	1	2	3	4	5
22.	Having sufficient science content knowledge to facilitate classroom discussions	1	2	3	4	5
23.	Monitoring student understanding through traditional assessment practices	1	2	3	4	5
24.	Using assessment practices to modify science teaching	1	2	3	4	5
25.	Developing strategies to teach nature of science	1	2	3	4	5
26.	Assessing students' understandings from laboratory/hands-on learning	1	2	3	4	5
27.	Ability to plan successful inquiry-based activities/learning	1	2	3	4	5

1 = no discontentment
2 = slight discontentment
3 = moderate discontentment
4 = significant discontentment
5 = very high discontentment

28.	Balancing personal science teaching goals with state/national testing requirements	1	2	3	4	5
29.	Orchestrating a successful balance between covering a wide range of material and engendering deep student learning	1	2	3	4	5
30	Balancing personal science teaching goals with those of national standards	1	2	3	4	5

III. Rating Areas of (Dis)Contentment

Please rank the following issues with regard to your current level of discontentment, with #1 being the aspect of your teaching with which you are most discontented and #5 being the aspect with which you are least discontented. In other words, rank these practices according to how (dis)contented you are with your ability to successfully use them to achieve your teaching goals.

_____ Teaching inquiry-based science.

_____ Teaching across all student ability-levels.

_____ Resolving depth vs. breadth content issues.

_____ Assessing student learning.

_____ Your own level of science content knowledge.

Appendix

G. Follow-up Interview Protocol

Follow-up Interview Protocol

Participants will be shown their two questionnaires and asked to elaborate or clarify their responses, as needed. They will be asked first to read their response and add additional comments if they choose. Particular statements needing clarification by the researcher will be identified, and the participant will be asked to explain further or provide an example. Interview questions will vary with participant because of the dependency on the participant's individual responses. Typical questions based on item responses include:

1) "Can you explain what you mean by "______" in your response to question _____?"
2) "You mention that you make decisions based on the validity of the data you collect. How do you determine what data are valid?
3) What do you mean in your answer to number 4? Can you give an example to help me understand what you are thinking?
4) Have any of your ideas changed since you filled out the questionnaire? If so, can you explain how and why?
5) Have you thought about these types of issues before? If so, when?
6) How do you feel about yourself before, during and after the 1-week science camp?
7) Do you think that this 1- week science camp is effective to improve your understanding about NOS? How? Please explain.

Appendix

H. Exit Interview Protocol

Exit Interview

Teaching experience

1. How do you think your teaching went over the two weeks?

2. How did the team teaching work?

3. What about the role of the mentor teacher? What did you see as their role? How did that benefit you?

4. How about your planning? How did you use your plans while teaching?

5. How prepared did you feel going into the two weeks of teaching? What helped you get prepared?

6. What was one of the toughest parts where you felt the least prepared?

5. Compare teaching week one to teaching week 2: How did your views of teaching or abilities to teach change over the two weeks?

6a. Teaching – What do you see as your main strengths?

6b. What do you think you still need to work on as a teacher?

Program components influence on teaching:

8. Did you think about things from the 3030 course during your teaching? [how did the course prepare you for your teaching?]

9. How do you think your research played a role in your teaching?

10. How do you see all three components of the program fitting together? [research, course, teaching]

10b. What do you think the role of the scientist should be in science education?

Identity:

11a. When you think of yourself and your career, how do you identify yourself? [there can be multiple identities]

11b. At this point in the program, do you identify yourself as [feel like] a scientist? Explain.

11c. At this point in the program, do you identify yourself as [feel like] a teacher? Explain.

11d. Which do you feel you identify with more: scientist or teacher or equally both? Why do you think that?

NOS/NOSI concepts and PCK

12a. . What does NOS mean to you?

12b. When you are going to teach NOS, what do you think is important to teach? Why?

12c. How do you go about teaching NOS?

12d. What part of <u>(use any of the NOS ideas)</u> did you use in your teaching?

13a. What does Scientific inquiry mean to you?

13b. When you are going to teach about scientific inquiry, what do you think is important to teach? Why?

13c. How do you go about teaching scientific inquiry?

13d. What parts of inquiry did you use in your teaching?

14. [After they answer, show the chart with the inquiry teaching elements and ask about those elements specifically]

15a. Show them their post course questionnaires and take some time to read their answers, change anything they want to change. Then discuss why they did not change (what have they experienced that reinforced their views?) and why they changed (what have they experienced since the course that changed their views?).

15b. How did their teaching experience impact their views of NOS/NOSI/inquiry teaching?

16. Show them their CoRe post survey, and ask about the questions that survey has. (try to find out the connection between their understanding of NOS/NOSI and teaching practices based on the questions that CoRe has.)

16a. What kind of difficulties did you have when you are teaching NOS or NOSI? (try to elicit reasons of difficulties) (and how to handle them to solve)

16b. if you are going to teach NOS or NOSI in the future, what part of your teaching you want to change or add?

Then ask about the following aspects as necessary. Be sure you have a good sense of where they are with respect to all the NOS and NOSI aspects.

17. Theories and Laws

Describe and give examples

18. Creativity

19. Tentativeness

20. Subjectivity: When scientist all do the same thing but come up with different ideas; How does that happen?

21. Models – Did you use any models in your class? How would you define what a scientific model is?

22. Scientific Method –

23a. Justification

23b. Anomalies – What do you think the relationship is between real science and the science classroom?

24a. Do you see connections or relationships between NOS aspects? NOSI aspects? Explain. [Show them the NOS/NOSI charts for them to refresh their memory of the aspects]

24b. Show them their NOS concept map from class: Do they want to make any changes?

For example: How does the subjective NOS relate to the tentative NOS?

Then choose two more aspects and ask how they might relate….and so on.

25. What kind of factors did mostly influence your understanding and teaching of NOS and NOSI? (then show them thefactors table that Gunkut created)and talk about these factors. (try to elicit reason of why)(ask them if they have another factors)

Wrap up of program outcomes:

26. What do you consider effective science teaching now?

27. Consider the whole year program… What is going to stick with you most?

28. What was your least favorite part of the program?

29. What suggestions do you have for making the program a better experience?

30. So what are your future plans?

31. Any ideas about going into teaching/research now?

32. What pseudonym would you like us to use for our reporting?

Appendix

I. Daily Reflection Protocol (Teaching Observation)

Daily Reflection Protocol (Teaching Observation)

1. What class did you observe today?
2. What do you think the teachers did well today? Give examples.
3. How do you think the teaching could have been improved today? Give examples.
4. What did you learn about students today? Give examples.
5. What are two questions you have about teaching or learning based on what you observed today?
6. Are the lesson plans going as well as the teachers have planned?

Appendix

J. Teaching Reflection Assignment

Teaching Reflection Assignment

Teaching Reflection Assignment

After you teach your lesson, watch your video several times (without sound, with only sound, regular). Reflect on the process of teaching your lesson and respond to the following questions in detail.

1. **General teaching approach and effectiveness:**

   a). Describe your general reaction to your experience teaching this lesson for the first time.

   b). Describe how clear your lesson was. Write down at least <u>two specific examples</u> of times during the lesson that were clear or not clear.

   c). Did you follow your lesson plan or deviate from it in places? Explain how you used your lesson plan and when/why you deviated from it. How will you need to revise your lesson plan?

   d). What evidence do you have that the students achieved your expected learning outcomes? Be specific with examples from your teaching video.

   e). How well prepared did you feel to teach this lesson? Describe your feelings before and during the lesson.

   1) What areas of teaching science do you feel most comfortable with? Why?
   2) What areas of teaching science do you feel least comfortable with? Why?

2. **Elements of inquiry teaching:**

   (a) What elements of inquiry teaching did you explicitly include in the teaching of your lesson? [refer to the inquiry analysis tool, or the list of scientific practices on the NOS/NOSI checklist). Give specific examples from your teaching that represents these elements.

   (b) Listen to the types of questions you are asking.

   1) Describe the types of questions you used. Be specific with examples of open-ended questions where the students can explain their ideas and any that were more focused on a getting a particular answer (one word or yes/no). Which type did you use more frequently? Why?

   2) How did you follow up to student responses? Give examples.

   3) Write down a few good questions that were asked that you want to make sure you include in the final version of your lesson.

   4) Also write down some not so good questioning strategies you saw and describe how these questions could be asked differently.

   c). How prepared do you feel to teach **inquiry-based** science?

   1) What areas do you feel most comfortable with? Why?
   2) What areas do you feel you need to work on most? Why?

   d). How did your summer research experience help you to plan and teach your lesson? Explain what knowledge and/or skills from the summer research you are able to use to help with your teaching.

1. **Self-reflection**: **Look at the part of the lesson that you taught, specifically.**

   a) Describe three specific things about your teaching that you thought you did well. Why do you think you were successful in these areas?

   b) Describe three specific things about your teaching that you want to work on or improve. Why do you think you struggled in these areas?

2. **NOS and NOSI instruction (refer to the NOS/NOSI checklist or the inquiry analysis tool)**

   a) Describe where in your lesson you explicitly addressed one or more NOS or NOSI aspects.

      1) What aspects were addressed? Be specific about what aspects.
      2) How did you teach them? Be specific about when and how you taught these aspects.
      3) How did students understand these aspects? Give evidence for student learning.

   b) Describe specific opportunities during your lesson that you could include explicit teaching about one or more aspects of NOS and NOSI.

      1) What aspects could you teach?
      2) How could you teach them? (Where in the lesson and what would you do to teach the aspect(s)?
      3) How could you assess their understandings of the NOS and NOSI aspects?
      4) Why do you think you did not include these aspects in your lesson plan before?

   c). What resources are helpful to you when you are planning to include NOS and NOSI in your lessons? (e.g. the class activities, readings, websites, discussions, research experience, etc.)

   d). How comfortable do you feel about the concepts of NOS and NOSI?

      1) What aspects are easiest for you to understand? Explain why.
      2) What aspects are you still struggling with? Explain why.

   e). How comfortable do you feel about teaching the concepts of NOS and NOSI within your science lessons?

3. **Other comments:** Describe any other observations, thoughts, or questions you may have related to your science teaching.

Appendix

K. An Example of Explicit Reflection NOS Instruction (Tube Activity)

An Example of Explicit Reflection NOS Instruction

Sample activity and explicit NOS instruction Activity	Aspects targeted	Example of Explicit Approach (taken from Schwartz et al. 2007)
The Tube (included constructing their own models) (Lederman & Abd-Ek-Khalick, 1998)	Observation/ inference	The start of the activity involves showing students a tube with the ends sealed and four ropes protruding from the sides, two at the top and two toward the bottom. When a rope is pulled, the others slide into the tuber (a knot prevents the ropes from going all the way into the tube). No matter what rope is pulled, the others go in. The students make observations of this behavior. Students often make inferences rather than observations. When this happens, we ask if they are making an observation or inference, or if they can observe what they are saying. Example: S: The ropes are somehow tied together in the tube. T: What makes you say that? S: Because when you pull one, the others move. So they must be connected. T: Ok. Then what do you observe? S: The ropes moving. T: What then did you infer from that observation? S: That they must be connected. T: Ok. So is there a difference then between what is observed and what is inferred? S: Observed is what you see. Inferred is what you can't see but what you think is going on to make what you can see happen. T: Ok, that pretty well explains the difference. Your inference that the four observed ends of rope are somehow connected inside the tube. This inference is based on your observation of the movement of the ropes on the outside of the tube. You did not directly observe that they were connected, did you? But you can support your inference that they are connected based on what you are able to observe. [We often make two columns on the board as students make observations and inferences. We discuss differences. We discuss the need for inferences to have supporting observations. This introduces the concept of "evidence."
	Subjectivity	Students propose reasons for why the tube behaves the way it does. We verbally share ideas as a class. If someone does not make the proposal, we ask if they think a little man may be in the tube, pulling and pushing the strings as we manipulate the outside? This usually gets a laugh, but that is the point. T: Why do you laugh at the idea of a little man inside here? S: Because he couldn't breathe. T: Oh, sure he could. There is enough space at the holes for air to get in. Or maybe he has on a little oxygen tank. S: There is no such thing as someone that small. T: Oh, so my idea isn't a good idea because we have never seen a little man? Wouldn't it work though? S: Yes, but it isn't a good explanation because it doesn't make sense. T: There you go. It doesn't make sense with how we understand and accept the world to be. My idea would work, sure. But it is not a valid explanation of the mechanism of the tube because it does not fit within our theoretical framework of what is possible. Therefore, not all claims are equally valid. Some fit "better" than others. We have expectations and perspectives that influence how we explain the world. Do scientists have expectations and perspectives that influence how they explain the world? S: Of course. T: Of course. This is what we mean by subjectivity in science. Scientists come to investigations with perspectives that align with current knowledge. That doesn't mean they all have the same perspective.

	Tentativeness	Students design and test their ideas of what is on the inside of the tube by making models. After students have tested their models against the "real thing" (my tube), we ask a series of questions: T: Are all the "working" models equally valid? (This generates discussion about what constitutes a valid claim in science.) T: Since we have some models that seem to be valid, do we know what is in the "real thing" (my tube)? S: Not necessarily T: Why not? S: Because there are different possibilities. T: Well, do you think we will ever know for sure? S: Yes, if you open up your tube. T: I can't do that. Just like at this time, we can't see into an atom. For the tube, you made observations, inferences, constructed and tested your models. If it works, does it matter if it matches the inside of mine or not? S: No. not really. T: Why not? S: Because it works. T: Again, what do we mean by "it works"? S: It does what yours does and we can make predictions that come true. T: Ok. But the model may not be exactly like the real thing. If we can't ever open up the tube, will we never know if we have it "right?" S: No. T: Does it matter? S: It might. If something else happens to make it not work anymore, then you know it is wrong. T: Ok. What do you think happens in that case? If there comes a time when the model no longer fits the observations? S: You have to find a new one that fits the new information. T: Ok, then we may never know if we have it "right" and that doesn't matter as long as the model is working for us. When additional information is available, or when perhaps we look at the data again in a different way, the model may have to be changed. Do you think that happens in real science? S: Sure. Scientists get new information. T: Ok. Then do you think science ever has or knows it has the absolute final "truth" ? Think about if we can never open the tube, but we must rely on the collected data and creative inferences. S: Maybe. T: Well, you just said new observations may make it necessary to change the model. Right? Will we ever be able to make every possible observation for all of time? S: No. T: Then is there a chance the model, or any scientific knowledge, may have to change in the future? S: No T: Ok. This is not to imply that scientific knowledge is flimsy. Don't forget we have a lot of observations and knowledge that went into the construction of the tube models. You just didn't make them up based on nothing. Science has basis in what we call empirical observations.

Appendix

L. Charlie's Demonstration Lesson Plan

Charlie's Demonstration Lesson Plan

Topic: Differentiating between chemical and physical change/reactions.

- Middle school level

Connection: Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred. [Clarification Statement: Examples of reactions could include burning sugar or steel wool, fat reacting with sodium hydroxide, and mixing zinc with hydrogen chloride.] [*Assessment boundary: Assessment is limited to analysis of the following properties: density, melting point, boiling point, solubility, flammability, and odor.*]

Expected Outcome: Students will be able to determine if a chemical or a physical change has occurred by observation.

Material Needed:

- 3 test tubes with lids (or any container) filled half full with water
- Food coloring
- 3 containers: 1 containing bleach, 1 containing vinegar, 1 containing hydrogen peroxide
- 3 droppers

Have the kids drop a couple drops of food coloring into each of the tubes containing water. Tell them you are going to add a different liquid to each of the 3 tubes of colored water and they have to decide if a chemical change happens or not. Have them take one dropper full of the vinegar and add it to one of the colored tubes. Cap and shake, or stir, the tube. Allow them to make any observations before repeating this process with the remaining 2 liquids and tubes. The bleach will produce a change in color indicating that a chemical change has occurred.

The containers where vinegar and H2O2 are added will not react while the bleach will react with the water and food coloring producing a chemical change. The change is indicated by the color change.

Flow: I will introduce the topic of chemical and physical change to the class asking what indicates a chemical change? Physical change? Once discussed I will lead the demonstration asking for observations on what is happening and if we believe that a chemical change has occurred. I will bring this back to the table that was made and see if what was witnessed as chemical/physical change coincides with what they originally said.

Assessment: There will be a questions and answer session where examples of changes are listed and the class will identify the change as chemical or physical.

Appendix

M. Rose's Demonstration Lesson Plan

Rose's Demonstration Lesson Plan

Chemical Reaction Demonstration

Topic: Gas chemical reaction
Standard:
MS-PS1-2: Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred

Learning outcome: Students will be able to identify evidence of a chemical change due to a gas formation.

Materials:
-20 oz. plastic bottle
-vinegar (2 tbl.)
-baking soda (1/4 c.)
-balloon
-funnel (optional, but not necessary)

Explanation:

During this experiment an acid; vinegar, is mixed with a base; baking soda. When these two substances are mixed, the reaction bubbles and produces a gas; carbon dioxide. As the reaction continues to occur, more carbon dioxide is produced, filling up and inflating the balloon attached to the top of the bottle.

Procedure:

-Standing in the front of the classroom, have all the students gather around the table. On the table is the bottle filled with vinegar, the balloon attached to the top of the bottle, already filled with baking soda. Make sure the students are ready to observe anything that happens.
-Lift the balloon, making sure all the baking soda empties into the bottle and let the students observe.
-Begin a class discussion...

> **What are some of the things you observed?** (a white powder coming out of the balloon, bubbling when the powder and liquid mixed, liquid turned from clear to cloudy, balloon inflating)
> **Was there any significance between when the bubbling stopped and when the balloon stopped inflating?** (the balloon stopped inflating when the bubbling stopped)
> **What do you think caused these things to happen?** (some sort of reaction occurred when the powder mixed with the liquid)
> **Is the change that occurred physical or chemical, how do you know?** (chemical because a gas was produced)
>
> **What would have happened if it was only a physical change?** (the balloon wouldn't have inflated, no bubbling would have occurred and the clear liquid would have mixed and turned from clear to cloudy)
> **Any ideas about what was mixed in the bottle?** (answers very broad)
> **Does anyone know the significance of why there was a reaction between these two products?** (a reaction occurred because it was a base reacted with a liquid and when these particular acid and bases are mixed, carbon monoxide is formed which causing the bubbling and the gas to inflate the balloon.

Assessment:

A formative assessment on the students learning would be done during the class discussion first. Then a more in-depth formative assessment would be done as a small writing prompt or exit slip where the students would have to explain what they saw happening in the bottle, why it happened and how it relates to gas chemical reactions.

Resources:
http://www.exploratorium.edu/science_explorer/bubblebomb.html

Appendix

N. Rose and Charlie's Lesson Plan for Day 1

Rose and Charlie’s Lesson Plan for Day 1

Name of Lesson: DAY ONE topic: Reaction in a Bottle			**Prepared by:** Charlie Rose
Resource: http://www.education.com/science-fair/article/balloon-gas-chemical-reaction/ http://www.exploratorium.edu/science_explorer/bubblebomb.html			**Date: 4/19/2014**
Topic: Gas Reaction	**Grade Level: 8th**	**Total time estimate: 2.5**	

Connections to NGSS:

MS-PS1-2. **Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.** [Clarification Statement: Examples of reactions could include burning sugar or steel wool, fat reacting with sodium hydroxide, and mixing zinc with hydrogen chloride.] [*Assessment boundary: Assessment is limited to analysis of the following properties: density, melting point, boiling point, solubility, flammability, and odor.*]

Overview/ Purpose/Assumptions:
During this lesson students will model what happens when baking a cake and apply that information with that of a gas reaction. They will then take this knowledge to help solve the bigger problem of why the cake didn’t rise from their lab modeling.

Content Learning Outcomes: Students will be able to identify evidence of chemical change through color, gas formation, solid formation, temperature change, and light. (Explained during the discussion after the investigation. See prompt questions.)

NOS Learning Outcomes:
Scientific Knowledge is Based on Empirical Evidence
Science knowledge is based upon logical and conceptual connections between evidence and explanations. (MS-PS1-2)
Students will explain the importance of having evidence to support claims.
Students will describe how different results are possible from the same investigation.
Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena
Laws are regularities or mathematical descriptions of natural phenomena. (MS-PS1-5)
A law is a description of what is happening while a theory is an explanation of why or how it happens. Ball falling, how gravity works.
Students will be able to describe the role of questions in guiding a scientific investigation.

NOSI Learning Outcomes: This lesson will clearly demonstrate inquiry and allow the students to differentiate between observation and inference. This lesion will also demonstrate sciences subjective and tentative nature and the use of creativity within the investigation process.

Science Practices Outcomes:
Developing and Using Models
Modeling in 6–8 builds on K–5 and progresses to developing, using and revising models to describe, test, and predict more abstract phenomena and design systems.
Develop a model to predict and/or describe phenomena. (MS-PS1-1),(MS-PS1-4)
Develop a model to describe unobservable mechanisms. (MS-PS1-5)

Level of Inquiry (on the Herron scale 0-3): Herron score-3

Connections to Inquiry and NOS: (explain where and how in the lesson your NOS, NOSI, and science practices expected outcomes are explicitly addressed.)
During the Cake Catastrophe activity we will introduce evidence, observation, and inference.
During the discussion post activity we will introduce the Law of Conservation of Mass and how it applies to the investigation, as well as detailing how subjectivity and tentativeness played a role during the investigation.

Materials required:
50 quart size Ziploc bags
Portion cups w/ lids
clear punch cups
5 balloons
Funnel
Big white boards
2 fl. oz. bottles
baking powder
baking soda
sugar
Water, hot and cold

measuring cups
measuring spoons

None of the products should be labeled

Safety Concerns:
Be respectful of classroom and classmates
Inside voices
Walking feet at all times
No horseplay
Goggles to be worn at all times during investigation
No eating, drinking or consuming any materials in lab, unless instructed otherwise.
All lab materials need to stay on tray during investigation, unless in use.
<u>Clean up</u>; all materials should be back on tray, trays should be return to their original spots, materials properly disposed of and table wiped down. (All materials use in this lab can be disposed of in the sink (liquid) or trash (solid/powders))
HAVE FUN!

Section of Lesson	**Time estimate**	**Teacher Guide** (what is the teacher doing)	**Planned questions, activities, & assessments**	**Student guide** (what are the students doing)
Opening	10 mins	*Ice Breaker: "Another Shoe Game" (BB)*	**Another Shoe Game** Everybody takes of a shoe from one side (lets say right side) and throw that shoe in a pile. Then everybody grab (at random) a shoe from the pile and put in on. Now the aim is to pair up the shoes. Each person must find the people who are wearing the same shoes as he/she is, and stand such that the pair of shoes are together. E.g. I'm wearing my shoe A and somebody's shoe G, I must find the person who is wearing the other shoe A, and stand so that pair of shoes are together (AA), and I must find	Students participate in ice breaker activity.

			someone wearing shoe G, and put my shoe G with his/her shoe G. Both shoes A and shoes G should be together in space and time (i.e. the object is to form a sort of a line or 'twister' kind of formation where all the shoes have been paired up.) At the end, pick one person, they need to introduce themselves, state which school they came from and the name of the persons shoe they took, that person then follows by introducing themselves and what school they came from and the person who's shoe they took, until all students have gone.	
	30 mins	*Leading the students in discussion, writing their thoughts on the board.* *-**Allow students to make guesses of what they think and have them write them on the right side of the board**. (BH)* *Student chosen at Teachers discretion. We will chose through hand raising and random selection. Involve everyone.*	(BB) "So to start today off fun, we were going to bake a cake <u>from scratch</u>, does everyone know what that means? We thought it'd be fun to have a special snack in class, however something went wrong when we baked it." *Show the failed cake, "What do you think went wrong?" (BH) "So today we going to conduct an experiments to figure out went wrong in the process of baking" (BH) "Before we begin our lab, we need to go over some guidelines that should be followed any time you're in a chemistry classroom." -Make a list of class rules, per student input **Expect to hear-** respect, inside voices, raising hands, no running, staying on task. **Required** – respect, appropriate behavior for a	Students are participating in discussion, sharing their ideas

		(BB) -Write down class rules to post for the whole week - Class rules are on lab sheet as well as on the left side of the white board.	chemistry lab (no running, safety goggles, no horse play), staying on task and making sure to handle materials appropriately.	
Body	60 mins	(BB) Discuss modeling. -What is a model and how is it useful? -Ask for and/or Give examples of models Discuss the importance of questioning in science- (BB) *Go over lab trays	(BB) "For our lab today, your job is to try and make a model to figure out what went wrong when baking the cake. (Use the student's ideas about what went wrong to generate questions). All investigations are driven by questioning. "How do you believe an investigation begins? What do you need?" How does a cake rise? What ingredients are used in a cake? Since we can't go back and see what happened or watch a cake baking in the oven, we are going to try and model it in the classroom. We have provided you with some different materials and it is your job to decide what to mix and how much of it is needed. Each cup has a certain amount of the substance in it, which is the most you can use of one product for a trial. Be sure to record what you are using	Begin lab exploration.

			and how much for each trial, along with your observations because everyone will present their findings after the exploration is done." *Provide clean up list for teacher to initial before leaving for break	
		Hand out lab sheet (BH) Begin the lab by handing out "Cake Catastrophe" lab sheet.		Students are grouped into pairs of two (partner is the individual sitting next to them…same side of table).
		(BH) Go over lab sheet and provided lab materials. Discuss observation and inference here. Pose the question of what is an observation? What is an inference? Can you give me an example of each? This should correspond to the observation/inference portion of the lab sheet. Assigning groups (pairs of two-table partner next to them) Revisit rules – Ask for repeat of the rules. Give	Pose the question of what is an observation? What is an inference? Can you give me an example of each? *This should correspond to the observation/inference portion of the lab sheet.	Students sharing ideas.

		simple situation, Ex. Run to the sink to clean up, and have the students address if it is correct or not and how it should have been done. *Have timer on screen set at roughly 45 minutes (http://www.online-stopwatch.com/countdown-timer/) Teacher will be moving through the class observing the students and asking questions as to what the students have decided to investigate. Questions should lead the students toward the goals of gas formation and the understanding of the reactions involved during the cake.	*Begin Lab EXploration "Why did you choose to start with that powder and that liquid?" "What do you think the powders/liquids are? What lead you to believe that? How does that relate to observation/inference?" "What do you thing went wrong with the cake? What EVIDENCE do you have? Introduce evidence to each group as you walk around the class room.	Explore various combinations of mixing water, vinegar, sugar and baking soda and baking powder. Student may use whatever amounts of products that are provided. Students are to write down all their observations, and record all amounts used. Students write their predictions and solutions on the board and prepare to discuss how they applied their model to the problem and what solution you think would fix the cake based on the evidence of the investigation.
Break				
Closing	45 mins	*Lead students in discussion* Teacher will choose	Have students present their findings from their exploration. -This will be done on the white board via a table. See attach table.	During discussion, students should present all their data on the white board in front of the class room. Each group will share their thoughts on how they

		group to present their findings with the class….have all groups write their findings on the board inside the projected table. Call groups up two at a time at teacher's discretion.	Oldest student will put their information on the board and the other member will then explain their findings when called on by the teacher. What were the differences between combining some of the products? Discuss which mixtures underwent a chemical reaction and physical change. How can you tell? What indicates a physical change? What indicates a chemical change? Go over the original objective. Have each group of students propose their "solution" to the objective; what is needed to make the cake rise? "What evidence do you have that supports your solution on "fixing" the cake?" "What is evidence?" "Why is evidence important?" -Discuss subjectivity and creativity, each group of students may have different models, and conclusions for what they think is needed (ie. Vinegar and baking soda or water and baking powder) Present new information; we will introduce a correct cake recipe and connect the ingredients of baking powder. Explain how vinegar would not be ideal for a cake due to taste. Vinegar	think we can "fix" the cake using evidence they gathered from their observations and inferences during the lab.

			also reacts really quickly…would this be ideal for a cake? Why not?	
			Cake should rise evenly over the entire time of baking.	
			-Discuss tentativeness after the addition of new information.	
			Ask the students if as they were doing the investigation, each time they either caused a reaction or not, did that change how they performed the next trial? Link this to subjectivity and tentativeness.	
			Wrap the lesson back to what happened with the cake. “How does this investigation relate to my cake problem?”	
		**Lead demonstrations for class to observe if necessary, or if students had other ideas they wanted to test, but didn’t have time for.*	Based off our experiment, how does this apply to baking and what could we have to done for the cake to bake properly. *If the students draw a blank, write out a list of ingredients and continue discussion from there.	
			Show a clip from the Magic School Bus chemistry episode	
		Show a clip from the Magic School Bus chemistry episode	*Give students a piece of cake to eat during the clip*	

		IF TIME ALLOWS *Introduce the topics of acids and bases and pH* *Discuss how baking powder works (baking powder contains an acid and a pase in powder form. When liquid is added the acids and bases go into solution (explain solution). This allows them to react. When an acid and a base react there is a gas formation and carbon dioxide and water are produced.* *Explain why acid base reactions are different than other reactions.* *-in an acid base reaction you are not using valence electrons (ask if they know what valence electrons are). Instead the movement of Hydrogen from one*	Show pH scale on the projector during explanation. PowerPoint on acid base materials. Give examples of where some common liquids fall on the pH scale. *this will be on the scale indicated with pictures. *Close up and have students complete an exit slip of an important fact for the day…add to resource after class*	

		molecule to another causes the reaction to occur. How easily this hydrogen molecule will move is called pH. *We use pH to measure how acidic or basic a solution is. This is measured with a pH scale that goes from 0-14; o being most acidic and 14 being most basic.*		
Extension activities (plans for early finishers)		*Walking around the classroom, assessing students finishing up labs. Monitoring students researching on the computer.*	Have students who finish early research, why did the products react the way they did in the bottle?	Students work individually on the computer, while other students
Assessment plans Exit Slip: What happened in the bottle and how do you know? How can we apply this to our everyday lives?				

Appendix

O. Rose and Charlie's Lesson Plan for Day 2

Rose and Charlie’s Lesson Plan for Day 2

<table>
<tr><td colspan="3">Name of Lesson: DAY TWO- Bouncy Ball Challenge</td><td>Prepared by:
Charlie
Rose</td></tr>
<tr><td colspan="2">Resource: Acid/Base Inquiry Lab Way2Go 2005
A WOW Lab Blueprint: Polymer Bouncy Balls</td><td></td><td>Date: 4/21/14</td></tr>
<tr><td>Topic: Solid formation resulting from chemical reaction</td><td>Grade Level: 8th</td><td>Total time estimate: 2.5 hours</td><td></td></tr>
<tr><td colspan="4">Connections to NGSS:

MS-PS1-2. Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred. [Clarification Statement: Examples of reactions could include burning sugar or steel wool, fat reacting with sodium hydroxide, and mixing zinc with hydrogen chloride.] [Assessment boundary: Assessment is limited to analysis of the following properties: density, melting point, boiling point, solubility, flammability, and odor.]</td></tr>
<tr><td colspan="4">Overview/ Purpose/Assumptions:
The students will be presented with a scenario of certain characteristics of rubber. With the information previously taught on acids and bases, the students will have to predict how to keep the rubber liquid, and how to solidify it, resulting a bouncy ball.
The groups will be respented with a basic lab protocol, each group will have to figure how the best pH to work with about how much of each to use. At the end of the lab, each student will produce their developed protocol and show their bouncy balls.</td></tr>
<tr><td colspan="4">Content Learning Outcomes: Students will be able to apply prior knowledge to solve a problem, develop and protocol to reach a specific outcome. The students will be able to understand different properties of bouncy balls and how they’re made by exploring how rubber reacts with acids and bases .</td></tr>
<tr><td colspan="4">NOS Learning Outcomes:
Scientific Knowledge is Based on Empirical Evidence
Science knowledge is based upon logical and conceptual connections between evidence and explanations. (MS-PS1-2)
Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena</td></tr>
</table>

Laws are regularities or mathematical descriptions of natural phenomena. (MS-PS1-5)

NOSI Learning Outcomes: We would like to demonstrate how we can model the same problem that Europeans had with bringing the rubber across the oceans years ago, while also using prior knowledge and how to reverse the same problem. Students will also demonstrate how multiple methods, may produce the same result and/or reach similar conclusions.

Science Practices Outcomes:
Analyzing and Interpreting Data
Analyzing data in 6–8 builds on K–5 and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.
Analyze and interpret data to determine similarities and differences in findings. (MS-PS1-2)
Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific knowledge, principles, and theories.
Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints. (MS-PS1-6)

Level of Inquiry (on the Herron scale 1-4): 3

Connections to Inquiry and NOS:
Students will be given a scenario and have to apply their own prior knowledge to reach a solution. They will have to use creativity and modeling while working through their own inquiry of the situation.

Materials required: (totals needed)
1 c. Lemon Juice (gallon)
1 c. Ammonia (gallon)
1 c. Drano (gallon)
1 c. Alcohol (gallon)
1 c. Cabbage juice (gallon)

5 pH paper (100 strips)
2. Tbs. Liquid latex
1 c. Water
measuring spoons
1 c. vinegar (solution with a pH 5) (2 gallons)
clear punch cups (200 cups)
Plastic spoons/ stirring sticks
food coloring (optional)

Safety Concerns:
Safety goggles, gloves
Review basic chemistry safety; no tasting anything, using appropriate amount of materials, washing hand and work area when lab is complete.

Section of Lesson	**Time estimate**	**Teacher Guide** (what is the teacher doing)	**Planned questions, activities, & assessments**	**Student guide** (what are the students doing)
Opening	10 mins	*(BH) Discuss basic properties of pH; acids and bases* **Have student share ideas regarding pH, acids and bases* *BB write ideas on board as BH leads discussion* *We use pH to measure how acidic or basic a solution is. This is measured with a pH scale that goes from 0-14; 0 being most acidic and 14 being most basic)*	Whole Group Discussion	Students are participating in discussion, sharing their ideas and thoughts about information on acids and bases.

	50 mins	*(Acids have pH values from 0-6, lower numbers mean stronger acids. Bases have pH values from 8-14. Higher numbers mean stronger bases. Neutrals are always right in the middle, pH value is 7)* *Explain to the students that we are going to do a short lab to explore acids and bases.* *BB Introduces mini lab *project timer on board; 40 mins*	Students will be provided with a tray of lab materials; clear punch cups and pH strips. All liquid materials will be provided on the counter (except cabbage juice). With their partner next to them, each group of student will test various liquids with the pH paper and make notes on their lab sheets. *As they are working, the teachers should be walking around and asking what they are noticing about their liquid. What is happening to the paper and what does this tell us about its pH. Take note of what liquid they test and then pose questions like, "What do you think would happen to the pH if you mixed two of the liquids?" Make sure they are noting any mixing, observations and pH recordings. *Once students have completed a number of pH test, pause the lab and explain that a new substance has come into the classroom,	With their partner sitting next to them, they explore some of the properties of acid and bases. All discussion ideas and observations should be noted on their lab sheets.

		Discuss questions as whole group	cabbage juice. Their job is to see how it interacts with the liquids and what relationship it has with pH and if there is any significance. Questions to ask throughout lab and discuss after lab What happens to the pH paper? *it change color depending on how acidic or basic the liquid is What happened to the pH when you mixed two of the liquids together? *gather results from the students (When we mix an acid with a base, the pH of the mixture becomes a more neutral value. Scientists have a word for this, it is called neutralization, and you should be able to get the pH to be close to 7. pH is a measurement that can change. If we add an acid to a base, they will react, and their pH will change. This is how scientists deal with dangerous acids and bases. They 'neutralize' them.) What happened when you introduced the cabbage juice with the liquids? *it changed them different colors Do you see significance with the color change? Maybe similar to that of the pH paper? *cabbage juice changes the liquid different colors, just like the pH paper.	Students share ideas and discoveries from lab during discussion

			When might knowing this come in handy? *when a scientists needs to determine the pH of a substance but doesn't have pH papers	
Break				
Body	15 min	*(BB) Introduce rubber scenario…* *"So class, when we were looking for an experiment to do for class today we came across this story…"*	*Project this story on the projector… Long ago, rubber was only available in jungles, because it was the sap of a rubber tree. The natives used to collect rubber tree sap into buckets, and then stand in the bucket. In a few minutes, the rubber would harden, and stick to the person's feet. This was a great way to get custom-made rubber shoes, and much better than walking everywhere barefoot. When colonists arrived from Europe, they were excited to learn about this tree. Rubber was also used by the natives to make waterproof fabric, and the Europeans didn't have any of that. So they collected some rubber tree sap themselves, packed it up in crates, and took it back to Europe by boat. When they opened the crates, the rubber had unfortunately solidified, and was not any good. So they went back to the jungle, and asked the natives how they got liquid rubber to last. The solution was simple; they always had a little boy pee in the bucket first. "The first question I want us to answer is, why	After listening to the story, students should do a think/pair/share with the students at their table.

	15 mins	*After the story is told, begin discussion* ***Project timer on the board for 15 minutes.*** *(BH) Discuss what students discovered in the mini-lab. They should have noticed that the bases made the rubber say liquid and the acids made the rubber solidify.*	did the boy pee in the bucket?" *Acid? Base? Gather student ideas "How can we test these ideas?" *As a class, develop ideas and a protocol for how they can model what the Europeans did and why they predicted they peed in the bucket. Provide the students with liquid latex allow them to test how acids and bases (these materials should still be on the counter) react with the liquid latex. Once students have tested an acid and base with the liquid latex, begin discussion Begin discussion and have students share what they discovered about the liquid latex, acids and bases. From what we observed, what can we then infer about why the boy peed in the bucket? *The boy peed in the bucket because urine is a base and it makes the rubber stay liquid. *Uncover urine label on chart and discuss variations of stronger/weaker acids and bases…discuss how science is tentative/subjective, long ago they may have thought urine was a base, but have now discovered it's a weak acid, or some scientist may still classify urine as a base, while others	All observations of how acids and bases react with liquid latex should be noted on their lab sheets.

		There should be empirical data collection as well as some observations Discuss significance of designing a protocol; details, steps, materials; anything another scientist	classify as a weak acid. "So now that we've figured out why the boy peed in the bucket and how the rubber is able to stay in liquid form until it gets to Europe, our next problem is, how can we get it back to rubber to make our products?" *Mix the liquid latex with an acid "Of the materials we've been working with so far, which of them are acids? And do they have the same acidity? *Review which materials are acids and there pH number? "So your next job is to figure out how to make rubber bouncy balls with our liquid rubber. On your lab sheet, you have an area that says, "Lab Protocol". This is where you need to note what materials you are using, how much of those materials and any important information about those materials, like maybe their pH for instance." I will give you one clue on what will help make your bouncy ball…once you have what acid you want to mix with the liquid latex, you're going to combine your acid and liquid latex in the cup, stir and once it solidifies, you're going to remove it, squeeze out the extra liquid with paper towel. *If you want to add food coloring, raise a hand and a teacher or intern will come around and add a few drops BEFORE you combine your	Begin lab exploration, students working in pairs. Students should be making observations and predictions to determine how they want to make their next bouncy ball. Students are answering probing questions that help connect the core ideas, thinking about where the bouncy ball is coming from. Reactants →products

		would need to replicate the same procedure. Lead students in discussion of protocols; which ones worked, which ones didn't, what can we change to produce a new and better one.	liquid and your latex. "Where did this new material come from?" "What happened to the starting materials?" Once you make your bouncy ball, you should explore and observe some of its properties. If it did not turn out the way you wanted it to, you may make some alterations to your protocol to discuss with the class Ask the students to compare their lab protocol with each of the members in the group. They will each have a different variable that was changed within the lab as to assess what caused the different bouncy ball.	Students test and discuss protocols
Closing	45 mins	*Lead students in discussion* *Discussion how*	Have students present their findings from their exploration. Ask the students to compare their lab protocol	

		creativity, modeling, observation, inference and the scientific method all play a role in this lesson Discuss how scientist use each other's information and protocols. Discuss the conservation of mass and energy	during whole group discussion. They will each have a different variable that was changed within the lab as to assess what causes higher bounce or decreased bounce. What were the differences between each of the labs and how do you think this affected the outcome (bounciness) of the experiment? How does each group of students bouncy balls compare to each other. Provide new protocol to make better bouncy balls. Discuss how all the starting material was not transformed or lost/created but were simply rearranged into a different chemical structure. Demonstrate how the original lab was different from their own investigation, making sure to highlight that sometimes different methods are needed to look into a situation, and sometimes there is a need to use both kinds of methods in conjuncture in order to get the best possible outcome. *Close up and have students complete an exit slip	Students follow new protocol for making bouncy balls
Extension		*Walking around the*	Supply students with information on thermal	Students work individually on the

activities (plans for early finishers)		*classroom, assessing students finishing up labs. Monitoring students researching on the computer.*	reactions to prepare for tomorrows lesson. (fun video on thermal chemical reactions)	computer, while other students finish
Assessment plans Exit Slip: How does the scientific method differ from an investigation of observation and inference? Is one method more correct/better than the other? Give an example of when one would be more practical or less practical than the other.				

Appendix

P. HSIRB Approval Letter

WESTERN MICHIGAN UNIVERSITY

Human Subjects Institutional Review Board

Date: May 18, 2015

To: Susan Stapleton, Principal Investigator
Renee Schwartz, Co-Principal Investigator
Cathy Northcutt, Co-Principal Investigator
Robert Ruhf, Co-Principal Investigator
Mary Ann Sydlik, Co-Principal Investigator
Brandy Skjold, Co-Principal Investigator
Gunkut Mesci, Student Investigator

From: Amy Naugle, Ph.D., Chair Amy Naugle

Re: HSIRB Project Number 11-05-29

This letter will serve as confirmation that the change to your research project titled "Experiencing Research for Teaching Science [ExpeRTS]: WMU-HHMI Preservice Science Teacher Program" requested in your memo received May 18, 2015 (to change dissemination to add Gunkut Mesci's dissertation) has been approved by the Human Subjects Institutional Review Board.

The conditions and the duration of this approval are specified in the Policies of Western Michigan University.

Please note that you may **only** conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: May 27, 2015

1903 W. Michigan Ave., Kalamazoo, MI 49008-5456
PHONE: (269) 387-8293 FAX: (269) 387-8276
CAMPUS SITE: 251 W. Walwood Hall

WESTERN MICHIGAN UNIVERSITY

Human Subjects Institutional Review Board

Date: June 26, 2014

To: Renee Schwartz, Principal Investigator
Susan Stapleton, Co-Principal Investigator
Cathy Northcutt, Co-Principal Investigator
Robert Ruhf, Co-Principal Investigator
Mary Ann Sydlik, Co-Principal Investigator
Brandy Skjold, Co-Principal Investigator
Gunkut Mesci, Student Investigator

From: Amy Naugle, Ph.D., Chair Amy Naugle

Re: HSIRB Project Number 11-05-29

This letter will serve as confirmation that the change to your research project titled "Experiencing Research for Teaching Science [ExpeRTS]: WMU-HHMI Preservice Science Teacher Program" requested in your memo received June 25, 2014 (add student investigator Gunkut Mesci) has been approved by the Human Subjects Institutional Review Board.

The conditions and the duration of this approval are specified in the Policies of Western Michigan University.

Please note that you may **only** conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: May 27, 2015

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