A Study of Elementary Teachers’ Conceptions of Nature of Science and Their Beliefs about the Developmental Appropriateness and Importance of Nature of Science throughout a Professional Development Program

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A STUDY OF ELEMENTARY TEACHERS' CONCEPTIONS OF NATURE OF SCIENCE AND THEIR BELIEFS ABOUT THE DEVELOPMENTAL APPROPRIATENESS AND IMPORTANCE OF NATURE OF SCIENCE THROUGHOUT A PROFESSIONAL DEVELOPMENT PROGRAM

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Abstract

A Study of Elementary Teachers’ Conceptions of Nature of Science and Their Beliefs about the Developmental Appropriateness and Importance of Nature of Science throughout a Professional Development Program

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This qualitative study aimed to explore the changes in elementary science teachers’ conceptions of nature of science (NOS) and their beliefs about the developmental appropriateness and importance of NOS after participating in an academic, year-long professional development program (PDP) as well as the factors facilitating these changes. The PDP consisted of two phases. In the first phase, the participants received NOS training designed with an explicit-reflective instructional approach. In the second phase, the participants implemented several NOS training activities in their classrooms. Four elementary science teachers who volunteered and completed all components of the PDP (i.e., the NOS training and the NOS teaching) comprised the participants of the present study.

A multiple-embedded case study design was employed to explore the changes in the elementary science teachers’ conceptions of NOS and their beliefs about the developmental appropriateness and importance of NOS. The study data were collected
from multiple sources. The primary data sources included (a) Views of Nature of Science Elementary School Version 2 (VNOS-D2) questionnaire (Lederman & Khishfe, 2002), (b) Ideas about Science for Early Elementary (K-4) Students questionnaire (Sweeney, 2010), and (c) follow-up semi-structured interviews. The secondary data sources included videotaping of meetings with teachers, reflective field notes, and artifacts produced by teachers and their students. Data were analyzed using Yin’s (1994, 2003) analytic tactics of pattern matching, explanation building, and cross-case synthesis.

The findings of the study revealed that the elementary science teachers showed gradual, but substantial changes in their conceptions, and beliefs about the developmental appropriateness and importance of the NOS aspects over the course of participation in the PDP. Moreover, the participants identified nine components in the PDP that facilitated these changes in their conceptions, and beliefs about the developmental appropriateness and importance of the NOS aspects. These components were (a) specific focus on the NOS content, (b) participation in hands-on activities on NOS, (c) educational readings on NOS, (d) multiple types/ formats of reflection, (e) multiple exposure to the NOS content, (f) structural consistency in the presentation of the NOS content, (g) the evaluation of secondary student data, (h) the analysis of national and state science standards in terms of NOS, and (i) the implementation of the NOS activities in the classroom. Based on the findings of this study, it may be concluded that explicit-reflective NOS instruction coupled with NOS teaching is sufficient to evolve and crystallize teachers’ conceptions and beliefs about the developmental appropriateness and importance of the NOS aspects.
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Table of Contents

Abstract..................................................................................................................................................III

Acknowledgements .................................................................................................................................. V

Table of Contents ...................................................................................................................................... VI

List of Tables .............................................................................................................................................. X

Chapter 1 Introduction to The Study........................................................................................................1

Introduction.............................................................................................................................................1

Rationales for Teaching NOS..................................................................................................................2

The Status of NOS Understanding Among Students and Teachers.................................................10

Teaching as a Remedy to Increase the Level of NOS Understanding.............................................11

Importance and Challenges of Teaching NOS in Elementary Classrooms....................................12

Elements of NOS Understanding for Elementary Science Teachers.............................................12

Statement of Problems in the Literature on Elementary Teachers’ NOS Learning..........................18

Study Purpose.......................................................................................................................................20

Significance of the Study..........................................................................................................................21

Chapter 2 Literature Review ..................................................................................................................22

Introduction.............................................................................................................................................22

Research on NOS Learning of Elementary Science Teachers.......................................................22

Research on Conceptual Change.........................................................................................................59

Research on Effective Professional Development Programs.........................................................67

Chapter 3 Methodology..........................................................................................................................79

Introduction.............................................................................................................................................79
Design of the Study .................................................................................. 80
Setting ......................................................................................................... 82
Participants ............................................................................................... 83
Data Sources ............................................................................................. 85
Professional Development Program ......................................................... 95
Data Collection ......................................................................................... 98
Data Analysis ........................................................................................... 100
The Quality of Research ......................................................................... 102

Chapter 4 Findings .................................................................................. 109
Introduction ............................................................................................. 109
Research Question One ........................................................................... 109
Pre-NOS Training NOS Conceptions ....................................................... 110
Post-NOS Training NOS Conceptions ....................................................... 128
Post-NOS Teaching NOS Conceptions ...................................................... 153
Research Question Two .......................................................................... 183
Pre-NOS Training Beliefs ....................................................................... 184
Post-NOS Training Beliefs ..................................................................... 205
Post-NOS Teaching Beliefs ..................................................................... 230
Research Question Three ....................................................................... 252

Chapter 5 Discussions and Implications .................................................. 266
Introduction ............................................................................................. 266
Study Overview ......................................................................................... 266
Research Question One .......................................................................... 267
List of Tables

Table 1. Francine’s Pre-NOS Training Ratings for the Developmental Appropriateness and Importance of Teaching Ideas about Science for her Third Graders ...............185

Table 2. Anna’s Pre-NOS Training Ratings for the Developmental Appropriateness and Importance of Teaching Ideas about Science for her Fifth Graders.......................189

Table 3. Nancy’s Pre-NOS Training Ratings for the Developmental Appropriateness and Importance of Teaching Ideas about Science for her Fifth Graders.........................193

Table 4. Andy’s Pre-NOS Training Ratings for the Developmental Appropriateness and Importance of Teaching Ideas about Science for his Fifth Graders.........................196

Table 5. The Participants’ Pre-NOS Training Ratings for the Developmental Appropriateness and Importance of Teaching the Ideas about Science .........................204

Table 6. Francine’s Pre- and Post-NOS Training Ratings for the Developmental Appropriateness and Importance of Teaching Ideas about Science for her Third Graders ..........................................................................................................................210

Table 7. Anna’s Pre- and Post-NOS Training Ratings for the Developmental Appropriateness and Importance of Teaching Ideas about Science for her Fifth Graders ..........................................................................................................................214

Table 8. Nancy’s Pre- and Post-NOS Training Ratings for the Developmental Appropriateness and Importance of Teaching Ideas about Science for her Fifth Graders ..........................................................................................................................217
Table 9. Andy’s Pre- and Post-NOS Training Ratings for the Developmental Appropriateness and Importance of Teaching Ideas about Science for his Fifth Graders .................................................223

Table 10. The Participants’ Pre- and Post-NOS Training Ratings for the Developmental Appropriateness and Importance of Teaching the Nine Ideas about Science .................229

Table 11. Francine’s Pre-NOS Training, Post-NOS Training (Post1), and Post-NOS Teaching (Post2) Ratings and Rankings for the Developmental Appropriateness and Importance of Teaching the Ideas about Science for her Third Graders .....................234

Table 12. Anna’s Pre-NOS Training, Post-NOS Training (Post1), and Post-NOS Teaching (Post2) Ratings and Rankings for the Developmental Appropriateness and Importance of Teaching the Ideas about Science for her Fifth Graders .....................240

Table 13. Nancy’s Pre-NOS Training, Post-NOS Training (Post1), and Post-NOS Teaching (Post2) Ratings and Rankings for the Developmental Appropriateness and Importance of Teaching the Ideas about Science for her Fifth Graders .....................243

Table 14. Andy’s Pre-NOS Training, Post-NOS Training (Post1), and Post-NOS Teaching (Post2) Ratings and Rankings for the Developmental Appropriateness and Importance of Teaching the Ideas about Science for his Fifth Graders .....................247

Table 15. The Participants’ Pre- and Post-NOS Teaching Ratings for the Developmental Appropriateness and Importance of Teaching the Nine Ideas about Science .............251
Chapter 1 Introduction to the Study

Introduction

It is widely claimed that the goal of science education is to achieve scientific literacy (DeBoer, 2000). In this regard, several American national science education reform documents, including the *Benchmarks for Science Literacy* (American Association for the Advancement of Science [AAAS], 1993, 2009) and the *National Science Education Standards* (National Research Council [NRC], 1996) explicated the goal of scientific literacy. Acknowledging that there is no universal definition of the term scientific literacy since its first introduction in the late 1950s, in the broadest terms it can be defined as “what the public should know about science in order to live more effectively with respect to the natural world” (DeBoer, 2000, p. 594).

For a better understanding of the vision of scientific literacy in science education that promotes public understanding of science, we must first answer what science is. Science can be conceptualized in three domains: (a) a body of knowledge about the way the natural world functions (content), (b) a wide range of methods and processes used in the production of this scientific knowledge (process), and (c) knowledge about the way the scientific endeavor functions (ideas about science) (NRC, 2000). The third domain in this triad that describes the values and assumptions inherent to the development of scientific knowledge is referred to as *nature of science* (NOS) (Lederman & Zeidler, 1987). More specifically, it answers questions such as “What is science?”, “How does science operate?”, “How do scientists work as a social group?”, and “How does society itself both shape and react to scientific endeavor?” (McComas, Clough & Almazroa,
With that being said, an understanding of NOS is considered as a key component of scientific literacy (NRC, 2000).

**Rationales for Teaching NOS**

There are two main reasons for why it is important to teach NOS. The first rationale is that the major science education reform documents in the United States and various science educators around the world have argued the importance of understanding of NOS to achieve the scientific literacy vision of science education. The second rationale is related to the fact that research studies have provided evidence for the importance of NOS understanding to enhance the learning of science content and to inform the process of decision making about socioscientific issues. The following two sections are devoted to the discussion of the importance of including NOS in K-12 science education.

**Science education reform documents and science educators highlight the necessity of teaching NOS for the vision of scientific literacy.** Since 1980s, raising scientifically literate citizens who can understand NOS has been considered as one of the desired outcomes of K-12 science education in the United States (NGSS Lead States, 2013). For instance, the Benchmarks for Science Literacy (AAAS, 1993, 2009) is one of the tools of the Project 2061 that provided recommendations for what K-12 American students should know and be able to do in science, mathematics, and technology to progress toward the scientific literacy goals outlined in the project’s 1989 report Science for All Americans (AAAS, 2013). This national reform document demonstrates the importance of including NOS in the science curriculum by devoting a specific section for the Nature of Science. Similarly, the National Science Education Standards published by National Research Council in 1996 explicate the History and Nature of Science as one of
the eight content standards to be taught during K-12 science education. Recently, Next Generation Science Standards (NGSS) (NGSS Lead States, 2013) have a specific chapter for Understanding the Scientific Enterprise: the Nature of Science. This consistent integration of NOS into the science education reform documents in the United States justifies teaching NOS for students of all ages.

In addition to the national science education reform documents (AAAS, 1993, 2009; NRC, 1996; NGSS Lead States, 2013), several science educators have also suggested the inclusion of NOS to promote scientific literacy for all students, and hence, public understanding of science. For instance, Driver, Leach, Millar, and Scott (1996) identify five important arguments for why citizens should understand NOS:

- A utilitarian argument (the necessity of NOS understanding to better understand science and manage the technological objects and processes from daily life).
- A democratic argument (the necessity of NOS understanding to make sense of socio-scientific issues and participate in a democratic decision-making process).
- A cultural argument (the necessity of NOS understanding to appreciate science as a major element of contemporary culture).
- A moral argument (the necessity of NOS understanding to understand the norms of the scientific community, embodying moral commitments which are of general value).
- A science learning argument (the necessity of NOS understanding to support successful learning of science content).

The utilitarian and democratic arguments presented by Driver and others (1996) show consistency with the necessity of NOS understanding for citizens to become critical
consumers of science that is supported by the *Benchmarks for Science Literacy* reform
document. According to AAAS (2009), when students know how scientific knowledge is
generated, and how such knowledge is limited, they would be inclined to consider
scientific claims thoroughly rather than rejecting them recklessly or accepting them
uncritically.

Being endorsed in the science education reform documents and by science
educators as an integral component of the vision of scientific literacy is only one rationale
for teaching NOS. The following section provides evidence in the research literature that
supports teaching NOS.

**Research support teaching NOS.** The research literature that justifies the
importance of teaching NOS can be combined under two broader categories: science
learning and decision-making. The following paragraphs provide more information about
the relationships between an understanding of NOS and science learning and decision-
making.

**NOS enhances the learning of science content.** Evidence supporting the science
learning argument (Driver et al., 1996; McComas et al., 1998) come from two lines of
research, primarily conducted with middle and high school students: (a) studies that
investigated the relationship between students’ epistemological beliefs (i.e., beliefs about
the nature of knowledge and learning) and their learning of science content (Qian &
Alvermann, 1995; Songer & Linn, 1991) and (b) studies that examined the relationship
between students’ understandings of models and modeling and their learning of science
content (Gobert et al., 2011; Sins, Savelsbergh, van Jooling, & van Hout-Wolters,
2008). All of these studies suggest that more sophisticated epistemological beliefs or
understandings contribute to better learning of science content. Considering that the term NOS typically refers to science as a way of knowing or epistemology of science (Lederman, 1992; Lederman, Wade, & Bell, 1998), it can be concluded that NOS should be taught in K-12 science education in order to promote science learning among students.

Specifically, Songer and Linn (1991) found that eighth grade students who viewed science as tentative (dynamic) rather than as a fixed body of knowledge (static) were more likely to integrate their understanding of physical science concepts (e.g., heat energy and temperature) across contexts such as school and everyday life. In other words, they revealed that middle school students’ beliefs about scientific knowledge predicted their knowledge integration in the domain of thermodynamics.

In another study, Qian and Alvermann (1995) examined the roles of both epistemological beliefs and learned helplessness in high school students’ learning of science concepts from text. Canonical correlation analyses showed that regardless of the kinds of prior knowledge students possessed about the science concept, the epistemological belief about the simple and certain knowledge was the most important predictor for conceptual change learning. In other words, the findings suggest that students who believe in simple and certain knowledge are less likely experience success in learning science than students who believe in complex and tentative knowledge.

In summary, research studies on epistemological beliefs (Qian & Alvermann, 1995; Songer & Linn, 1991) suggest that students’ understanding of NOS, particularly the tentative nature of scientific knowledge might contribute to better learning of science content. This conclusion seems to be supported by other studies (Gobert et al., 2011; Sins
et al., 2008) that addressed high school students’ epistemological understanding of models and modeling and its interaction with science learning.

For instance, Sins and colleagues (2008) investigated how the level of students’ epistemological understanding of models and modeling is related to the level of their cognitive processing during a modeling task in the domain of physics. They found a significant positive correlation between students’ understanding of models and deeper processing of material presented, whereas a negative correlation between students’ understanding of models and shallow processing of material presented. These findings mean that students who possess more sophisticated epistemological understanding of models and modeling are more likely to learn more from the task because they would employ more deep processes and fewer surface processes to do well on the task.

Different from Sins and colleagues (2008), Gobert and colleagues (2011) investigated the contribution of high school students’ understanding of models and modeling to their conceptual learning in the domains of biology, physics, and chemistry rather than to the level of cognitive processes they employed during learning in physics. Moreover, they explicitly stated that like many other researchers in science education they conceptualize epistemological understanding of models and modeling as an important component of NOS understanding. Therefore, Gobert and colleagues (2011) provided more direct evidence to what extent understanding of NOS related to models and modeling might promote science learning.

Gobert and others (2011) found that the relationships between students’ epistemological understanding of models and modeling and their content learning varied across different science domains. In particular, students’ epistemological understanding
of models and modeling did not influence their content learning in physics. In contrast, students who held more sophisticated understanding for models as multiple representations (i.e., those who acknowledge more that scientists might use more than one models to express the same scientific object or event) were also showed more gains in their chemistry content knowledge. Moreover, those students with a more sophisticated understanding for the changing nature of models (i.e., those who better understood that models may change over time with new evidence, data, findings, and theories or beliefs) also learned more biology. Given that understanding of the nature of models and modeling is considered a subset of NOS understanding, aforementioned findings suggest that students’ science learning is influenced by their understanding of NOS (i.e., the tentative and subjective nature of scientific knowledge).

The learning of NOS informs socioscientific decision-making processes of students. Research studies that investigated the relationship between an understanding of NOS and decision-making are limited and they show mixed findings. The works of Lederman and O’Malley (1990) and Bell and Lederman (2003) revealed that students’ decisions on controversial issues seem not related to their understanding of NOS. The results of these two studies should not be interpreted that teaching NOS is not important for decision making on socioscientific issues, given that there is no effective NOS instruction provided in these two studies. In particular, Bell and Lederman (2003) examined whether a group of college professors and a group of research scientists who held divergent views of NOS differed in their decisions related to socioscientific issues and the factors influencing their decision making. Lederman and O’Malley (1990), however, investigated the change in students’ beliefs about the tentativeness of scientific
knowledge and its relation to daily personal and societal decisions after one school year science instruction that was not designed to develop students’ views about science.

Unlike the aforementioned studies that found no relationship between understanding of NOS and decision making, some studies (Khishfe, 2012; Sadler, Chambers, & Zeidler, 2004; Zeidler, Walker, Ackett, & Simmons, 2002) revealed that some specific ideas about NOS seem to be related to socioscientific decision making. For instance, Zeidler et al. (2002) identified a few instances that manifested the relationship between NOS and decision making in the socioscientific issue of animal rights: (a) some students noted that the social and cultural influences affect how they view the scientific enterprise; (b) some students highlighted the importance of empirical evidence; even though, their views of the role of empirical evidence were narrow and one-sided; and (c) some students compartmentalized scientific knowledge and personal knowledge.

In another study, Sadler and others (2004) investigated how high school students’ socioscientific decision making was influenced by their ideas about NOS (i.e., the role of empirical evidence in the development of scientific knowledge, the tentative nature of scientific knowledge, and the influences of sociocultural context in the development of scientific knowledge). They assessed socioscientific decision making of students by soliciting their opinions about the scientific merit and persuasiveness of two articles that include conflicting information regarding global warming. The findings indicated that the interpretation and evaluation of conflicting information in the socioscientific context of global warming was influenced by a variety of factors related to NOS. Students’ interpretation of data and their beliefs about the sociocultural embeddedness of scientific knowledge influenced their socioscientific decision making. These findings, like the
findings of Zeidler et al. (2002) suggest that understanding of some specific ideas about NOS (empirical nature of science and sociocultural embeddedness of science) are more influential in decision making on socioscientific issues.

The findings of a more recent study conducted by Khishfe (2012) provided more promising evidence for the inclusion of NOS in school teaching because students in this study, unlike those in previous studies, were explicitly taught about NOS as well as how to use such acquired NOS understanding in decision making. The findings showed that ninth grade students did not always use their informed understanding of NOS when making a decision about the genetically modified food, yet they explained and justified their decisions about the genetically modified food by making references to three ideas about NOS (i.e., the empirical, tentative, and subjective nature of scientific knowledge).

In summary, the existing evidence from research with high school and college students and professors show that an understanding of NOS per se does not determine an individuals’ decisions; however, it informs them in the process of decision making related to socioscientific issues. Given explicit instruction on NOS and its application in decision-making, individuals use their understandings of certain ideas about NOS to explain and justify their decisions on socioscientific issues.

At this point, one might wonder to what extent we are successful in promoting contemporary NOS understandings among students and teachers given the fact that NOS is consistently deemed important by science education policy documents, science education community, and science education research for over five decades. The following section provides information about the status of students’ and teachers’
understandings of NOS to get more insights about the level of achievement in the vision of scientific literacy.

**The Status of NOS Understanding Among Students and Teachers**

In his comprehensive review of 50 years of research on NOS, Lederman (2007) concludes that both K-12 students and teachers possess conceptions of NOS that are not consistent with those recommended in the science education policy documents. Like these earlier studies in the history of NOS research literature, more recent studies with K-12 students (Akerson, Buck, Donnelly, Nargund-Joshi, & Weiland, 2011; Akerson & Donnelly, 2010; Akerson, Nargund-Joshi, Weiland, Pongsanon, & Avsar, 2014; Avraamidou, 2013; Bektas & Geban, 2010; Khishfe, 2008; Quigley, Pongsanon, & Akerson, 2010; Sharkawy, 2009; Walls, 2012) and teachers (Akerson, Cullen, & Hanson, 2009a; Akerson, Hanson, & Cullen, 2007; Akerson et al., 2009b; Buaraphan, 2010; Capps & Crawford, 2013; Iqbal, Azam, & Rana, 2009; Lotter, Singer, & Godley, 2009; Posnanski, 2010; Seung, Bryan, & Butler, 2009) have also resulted in the same conclusion that not only students but also their teachers hold many misconceptions about NOS. For instance, Buaraphan (2010) measured 113 preservice and 101 inservice science teachers’ conceptions of NOS related to scientific knowledge, scientific method, scientists’ work, and scientific enterprise. Similar to previous NOS research studies, they reported that the majority of preservice and inservice teachers supported the following flawed notions that: (a) laws are mature theories, (b) theories are less reliable than laws, (c) there is a universal, step-by-step scientific method, (d) accumulation of evidence makes scientific knowledge more stable, and (e) science is objective.
In addition to providing evidence for the consistent lack of NOS understanding among students and teachers, the corresponding research literature has also provided a remedy for this problem, which is explained in the following section.

**Teaching as a Remedy to Increase the Level of NOS Understanding**

Fortunately, evidence from research on NOS also demonstrate that including NOS instruction in classrooms has the potential to change both students’ and teachers’ misconceptions of NOS. For instance, Lederman and his colleagues aimed to enhance teachers’ abilities to improve their students’ learning of NOS and scientific inquiry via a teacher enhancement project, called Project ICAN: Inquiry, Context, and Nature of Science (Lederman et al., 2003; Lederman & Lederman, 2004). The analyses of both second and third year data indicated that participating in the project helped teachers to change not only their understandings but also their classroom applications of NOS and scientific inquiry. Subsequently, the findings also demonstrated major enhancements in their students’ understandings of NOS and scientific inquiry. More specifically, at the beginning of the project’s second year (Lederman et al., 2003) only 10% of the teachers demonstrated informed views in the role of imagination and creativity in the development of scientific knowledge. However, this number increased to 40% after the teachers participated in activities that addressed disciplinary and pedagogical knowledge related to NOS and scientific inquiry for one academic year. After their understanding of creative and imaginative NOS, teachers showed the most significant changes in their understandings of the tentative NOS (from 19% to 42%) and subjective NOS (from 19% to 35%). Like these teachers, as a result of instruction that explicitly addressed NOS and scientific inquiry about 40% of their students showed more informed views of NOS. The
most significant changes in students’ understanding of NOS were with respect to the inferential, empirical, and creative NOS.

In summary, the possibility that one’s misconceptions of NOS could change with appropriate instruction supports the argument that teaching NOS is necessary in science courses and teacher education programs to increase the level of NOS knowledge among students and teachers. The following section presents reasons for why teaching NOS is important particularly at the elementary level and some of the challenges specific to elementary science teachers in teaching NOS in their classrooms.

**Importance and Challenges of Teaching NOS in Elementary Classrooms**

Teachers of *all* ages are expected to know and convey an appropriate understanding of NOS recommended in the major science education reforms to their students during the schooling years (AAAS, 1993, 2009; NRC, 1996; NGSS Lead States, 2013). Given that some studies (Akerson et al., 2009a; McDonald, 2010) provided empirical evidence for the durability and persistence of preexisting views about NOS, it becomes even more important to start teaching NOS at early grades where students form their initial impressions of science. After elementary teachers start teaching NOS at early ages, secondary teachers can continue to emphasize and even teach more NOS to help their students exit high school with accurate views of science adopted in the reforms.

Unfortunately, in the elementary schools teaching science is not given much priority due to a disproportionate focus on improving kids’ mathematics and English standardized test scores and a lack of support for teaching science (Martindale, 2011). Elementary teachers and school principals are most likely to find teaching science as important as mathematics and English when their students start to be tested on this
content. Even teaching science is given importance in some elementary schools; elementary teachers do rarely consider the history and nature of science as an instructional objective to be given high emphasis during science instruction (Fulp, 2002). Moreover, Sweeney (2010) found that elementary teachers do not consider each of the ideas about NOS equally important to introduce in their classroom. More specifically, K-4 teachers, on average, perceived the ideas about the subjective NOS, the relationship between science and technology, the limits of science, and the distinction between theory and law as relatively less important than other ideas about NOS such as empirical or inferential NOS. Moreover, Sweeney (2010) showed that importance was a significant predictor of teachers’ introduction for all ideas about NOS of interest. With that being said, elementary teachers’ beliefs about the relative importance of science, or particularly NOS, might deter them to teach this content in their classroom practice.

In addition, science education at the elementary level is generally limited to concrete skills because of the teachers’ presumption that young children are not at appropriate developmental stages (Metz, 1995). In this regard, there is a growing body of research (Akerson et al., 2011; Akerson & Donnelly, 2010; Akerson & Hanuscin, 2007; Lederman & Lederman, 2004; Quigley et al, 2010) providing empirical evidence that with effective instruction students as young as kindergarteners can conceptualize ideas about NOS, which is at levels beyond what might be predicted by their developmental level. However, some ideas about NOS (e.g., science is empirical or inferential) are more readily available to them compared to others (e.g., science is subjective or socially and culturally embedded). Supportively, Sweeney (2010) found that at least 50% of K-4 teachers perceived all of the ideas about NOS as developmentally appropriate except for
the relationship between science and technology and the distinction between theory and law. Moreover, more than 90% of these K-4 teachers reported that the ideas about the inferential, empirical, and creative nature of science were developmentally appropriate for the grade level taught. Given that developmental appropriateness was found as a significant predictor of teachers’ inclusion of the ideas about science (Sweeney, 2010), it is crucial to help teachers of all ages to believe that their students are developmentally ready to grasp the ideas about NOS.

In order to help their students learn NOS, elementary teachers must also themselves have a firm grasp of this content in science. Unfortunately, the findings of national surveys within the last decade (Banilower et al., 2013; Fulp, 2002; Weiss, Banilower, McMahon, & Smith, 2001) consistently show that the majority of elementary teachers in the United States do not have strong content preparation in science. In particular, elementary science teachers were less likely to have undergraduate majors in science or science education and less science coursework than their middle and high school counterparts. Due to this lack of science backgrounds and experience elementary science teachers who provide young students with initial impressions in science were found holding more naïve views of NOS compared to secondary teachers (Morrison, Raab, & Ingram, 2009). Among various science teacher populations, elementary teachers, thus, are more likely to be ones who need professional development about NOS content the most. Following section presents research and reform-based recommendations about the elements of NOS content for elementary science teachers.
Elements of NOS Understanding for Elementary Science Teachers

There are three sources that can provide information about what kinds of ideas elementary science teachers and students should know about NOS. Given that the participants of this study were teachers in the United States, the NOS position statement of the National Science Teacher Association’s (NSTA) can be used as a reference to identify appropriate elements of NOS (Akerson, Buzzelli, & Eastwood, 2012; Akerson et al., 2009a; Akerson, Morrison, & McDuffie, 2006). In their position statement, NSTA (2000) lists several premises important to understanding of NOS:

- Scientific knowledge is both reliable and tentative: One can have confidence in scientific knowledge, though it is open to change and revision with new evidence or reinterpretation of old evidence and knowledge.

- There is no single, universal, step-by-step scientific method exists, but there are shared characteristics of scientific approaches: Scientific explanations are supported by empirical evidence and testable against the natural world and include observations, rational argument, inference, skepticism, peer review and replicability of work.

- Creativity plays a vital role in the production of scientific knowledge.

- Science is limited to the methods and explanations for understanding the natural world: Science cannot use supernatural elements in the development of scientific knowledge.

- Scientific knowledge is not entirely objective: Scientists’ backgrounds such as their prior experiences and knowledge and their social and cultural contexts might influence their work.
• There is a mutual relationship between science and technology.

• There is a relationship and distinction between scientific laws and theories: Both types of scientific knowledge are well-supported by the available evidence. Theories provide explanations of how the world works, while laws describe the way the world works. There is no hierarchical relationship between scientific theories and laws.

Given that American elementary teachers are required to help their students develop understanding of NOS that are in line with those recommended in the national science education reform documents (AAAS, 1993, 2009; NRC, 1996; NGSS Lead States, 2013), it is paramount to examine whether those elements espoused in the NSTA (2000) position statement are also recommended for elementary (K-5) students in these three reform documents. The review of the reforms shows that all of the above aspects, except for the last one, are recommended for K-5 students at least one of the three reform documents. This implied for the present study that American teachers are not required to teach about the functions of, and relationships, between theory and law at the elementary level. Such NOS understanding is more appropriate for higher-grade levels beyond K-5.

The last source of information that can provide information about appropriate NOS contents for elementary teachers is empirical research that focused on the changes in K-5 students’ understandings of NOS after receiving some types of NOS instruction. These intervention studies were mostly conducted by Akerson and her colleagues (Akerson & Abd-El-Khalick, 2005; Akerson et al., 2011; Akerson & Donnelly, 2010; Akerson & Hanuscin, 2007; Akerson et al., 2014; Akerson & Volrich, 2006; Quigley et
al., 2010), by Lederman and his colleagues (Lederman & Lederman, 2004; Lederman et al., 2003), and by other researchers (Avraamidou, 2013; Sharkawy, 2009).

The review of the aforementioned research literature showed that two of the premises deemed important in the NSTA’s (2000) NOS position statement were not the focus of any current NOS research with K-5 students. Empirical studies, consistent with the three reform documents (AAAS, 1993, 2009; NRC, 1996; NGSS Lead States, 2013), suggest that an understanding of NOS related to the functions of, and relationships, between scientific theories and laws is not important and/or appropriate for K-5 students. The second element that the research literature on NOS does not show an agreement with not only the NSTA’s (2000) position statement but also the three science education reform documents (AAAS, 1993, 2009; NRC, 1996; NGSS Lead States, 2013) is related to the relationship between science and technology because such understanding does not directly address epistemological growth of students (Zeidler, Sadler, Simmons, & Howes, 2005). In other words, students’ understanding of the relationship between science and technology is concerning another dimension of science content rather than NOS.

Lastly, an understanding of the limits of science was not examined in any of the NOS research studies with K-5 students; even though, it is recommended for students of all-age groups (K-2, 3-5, middle school, and high school) in the most recent science content standards (NGSS Lead States, 2013) and it is considered as a component of NOS understanding by some researchers (e.g., Southerland, Johnson, & Sowell, 2006).

In summary, this study conceptualized elementary science teachers’ understanding of NOS with respect to both science educators’ and researchers’ recommendations about NOS contents for K-5 elementary students. Thus, it targeted the
following nine aspects of NOS: the empirical, inferential, tentative, subjective, sociocultural, and collaborative NOS in addition to the limits of science and the absence of a single step-by-step scientific method. See Appendix A for the descriptions of the target nine aspects of NOS worded for elementary teachers by Sweeney (2010). The following section presents the problems of the attempts that have been recently undertaken to improve NOS conceptions of elementary science teachers.

**Statement of Problems in the Literature on Elementary Teachers’ NOS Learning**

It was well documented in the history of NOS research literature that elementary teachers do not have enough content knowledge about NOS (Lederman, 1992, 2007). Accordingly, both previous and recent studies have attempted to increase elementary teachers’ conceptions of NOS. However, the majority of such attempts either targeted preservice elementary teachers (Abd-El-Khalick, 2001; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & Akerson, 2009; Akerson, Abd-El-Khalick, & Lederman, 2000; Akerson et al., 2012; Akerson et al., 2006; Bell, Matkins, & Gansneder, 2011; Celik & Bayrakceken, 2012; Dass, 2005; Koening, Schen, & Bao, 2012; Matkins & Bell, 2007; Matkins, Bell, Irving, & McNall, 2002; McDonald, 2010; Salter & Atkins, 2013) or directed much of their attention to the translation of inservice elementary teachers’ newly gained conceptions of NOS in their classroom practices (Akerson & Abd-El-Khalick, 2003; Cullen, Akerson, & Hanson, 2010). Inservice teachers’ learning of NOS was the main focus only in two studies (Akerson et al., 2007; Morrison et al., 2009). Unfortunately, the intervention provided in these studies was very short (i.e., a two-week summer course or workshop) and underplayed the important role of testing out the theory in practice in teacher development. Moreover, only one of them (Akerson et al., 2007)
was specifically designed for increasing elementary inservice teachers’ understandings of NOS. Thus, there is a need for future research exploring practicing elementary teachers’ learning of NOS over an extended period time in a situation where the range of science content activities is aligned with the content that teachers are later required to teach in their classrooms.

Another limitation of the relevant literature is that most of the intervention studies (Abd-El-Khalick; 2001; Akerson et al., 2000, Akerson et al., 2007; Akerson et al., 2006; Celik & Bayrakceken, 2012; Cullen et al., 2010; Dass, 2005; Donnelly & Argyle, 2011; Koening et al., 2012; Matkins & Bell, 2007; Salter & Atkins, 2013; Shim, Young, & Paolucci, 2010) were designed to track just changes in the conceptions of NOS without determining which component(s) of the given intervention might have resulted in the detected changes. Thus, future research should also investigate the relative contributions of the components of the given intervention to teachers’ learning of NOS.

It is also well established in the literature that possessing enough NOS content knowledge is necessary, but not sufficient condition for teachers to help the development of their students’ NOS understanding (Lederman, 1992, 2007). Recent studies with elementary teachers (Akerson & Abd-El-Khalick, 2003; Akerson et al., 2009a; Akerson et al., 2009b; Donnelly & Argyle, 2011; Posnanski, 2010) and secondary teachers (Abd-El-Khalick, Bell, & Lederman, 1998; Bell, Lederman, & Abd-El-Khalick, 2000; Schwartz & Lederman, 2002) have furthered our understanding of the necessary conditions by identifying various factors not only related to cognition (e.g., previous knowledge about NOS and science content knowledge) but also related to motivation (e.g., the appreciation of the importance of teaching NOS) and context (e.g., the value of
teaching science at the teacher’s school). At this point, in addition to cognitive factors researchers should direct their attention to explore the amelioration of motivational or contextual factors to promote NOS teaching in science classrooms, and thus, promote students’ development of appropriate NOS understanding.

**Study Purpose**

As shown above, previous literature has highlighted the need for a NOS-oriented professional development program specifically designed for inservice elementary teachers. Such a NOS-oriented professional development program should include the following qualities: (1) it should be specific to elementary teachers’ grade level, (2) it should give elementary teachers enough time to acquire, reflect, and practice new ideas about NOS, and (3) it should motivate elementary teachers to teach about NOS. The present study furthered these lines of inquiry by investigating the following research questions:

(a) How did the inservice elementary teachers’ conceptions of NOS change over the course of participation in an academic-year long, professional development program, including NOS training and NOS teaching practices?

(b) How did the inservice elementary teachers’ beliefs about the developmental appropriateness and importance of the nine NOS aspects change over the course of participation in an academic-year long, professional development program, including NOS training and NOS teaching practices?

(c) What components of the professional development program did the elementary teacher perceive as effective in changing their conceptions and beliefs about the developmental appropriateness and importance of the nine NOS aspects?
Significance of the Study

This section provides a brief description of various significances of the study. First, this study contributes to the development and design of future professional development programs on NOS (a) by determining what might have contributed to the observed changes in the conceptions of NOS and beliefs about the developmental appropriateness and importance of NOS, (b) by investigating the influences of classroom practice and social interaction with students as an integral and key part of the professional development program, and (c) by assessing the effectiveness of the professional development program by taking into account not only cognitive but also motivational and contextual factors.

Second, the present study contributes to future NOS research by documenting learning process of elementary science teachers who generally have different teacher characteristics than their middle and high school counterparts and by investigating the teachers’ NOS learning not only during the NOS training but also after they teach NOS in their own classroom.
Chapter 2 Literature Review

Introduction

The present study is a combination of three different lines of educational research. The first is a line of research concerning elementary science teachers’ conceptions of NOS, such as how they comprehend what science is; how science operates; how scientists work as a social group; and how society itself influences and reacts to scientific endeavor (McComas et al., 1998). The second line of research deals with how and why individuals proceed to (or fail to) change their cognitive structure (i.e., conceptual change research). The third is a line of research concerning professional development of teachers, encompassing preservice or inservice teachers’ acquisition of skills and knowledge needed for effective classroom practices. The researcher strongly believes that teachers and researchers can get a better understanding of teachers’ learning of NOS if they mesh research on NOS learning of elementary science teachers with conceptual change research and professional development research, and conversely, conceptual change theory and professional development models can benefit by the understanding of the process through which elementary science teachers change (or fail to change) their conceptions of NOS. The following sections provide detailed information regarding each of these three lines of research that guided the present study.

Research on NOS Learning of Elementary Science Teachers

Before turning to examine the attempts undertaken to improve elementary science teachers’ conceptions of NOS, it is crucial to identify and clarify where the current study fits in the history of the NOS research. In his comprehensive review of NOS research for the last 50 years, Lederman (1992) claimed that after science educators and researchers
realized that students do not have adequate understanding of NOS (the major conclusion
drawn from the first line of research) and that the curricula designed to improve students’
conceptions of NOS seemed to give different results with different teachers (the major
conclusion drawn from the second line of research), they shifted their attention to the
assessment of, and attempts to improve, teachers’ conceptions of NOS. Within this third
line of NOS research, however, science educators were guided by the flawed assumption
that teachers will directly transfer their conceptions of NOS into their classroom
practices. With the realization that improving teachers’ conceptions of NOS is not
sufficient for promoting effective NOS instructions in the classrooms, science educators
and researchers headed to examine the relationships among teachers’ conceptions of
NOS, classroom practice, and students’ conceptions, which is the focus of the fourth line
of research (Lederman, 1992). Considering these four lines of research, efforts in the
third line of research are the foci of this section. However, it should be noted that these
current efforts do not assume that improving teachers’ conceptions of NOS will guarantee
effective NOS instruction in the classrooms. Therefore, some of these current efforts
reviewed in this section also show alignments with the fourth line of research. In other
words, the following review merges the third and fourth lines of research in the history of
NOS literature.

For the purpose of this review, the following electronic search engines relevant to
education and social science were utilized: EBSCO including Academic Search Premier,
Education Full Text, Education Resources Information Center [ERIC], PsycINFO,
PsycARTICLES, and SocINDEX with Full Text.
To locate studies that focused on elementary teachers’ learning of NOS, I searched EBSCO databases using the following terms: (a) “nature of science” AND “elementary” with a combination of “learning”, “effect”, “impact”, “influence”, “change”, “effectiveness”, “gain”, “improvement”, “development”, “professional development”, or “teacher development”; (b) “nature of science” AND “teachers” with a combination of “learning”, “effect”, “impact”, “influence”, “change”, “effectiveness”, “gain”, “improvement”, “development”, “professional development”, or “teacher development”; and (c) “epistemology of science” AND “teachers”.

The searches in the given search engines were limited to peer-reviewed articles with a full text. These searches resulted in over 500 articles, of which there was some overlap. Only empirical studies that examined the impacts of an intervention on teachers’ (i.e., preservice, inservice, or undergraduate/graduate students who plan to teach science in elementary schools) conceptions of NOS were selected for review. Those which focused on only pedagogical strategies and activities or the assessment of NOS conceptions, or those which did not include any elementary teachers or college/graduate students who plan to teach science in elementary schools, were excluded. Furthermore, the elementary studies that were included in the critical review of Abd-El-Khalick and Lederman (2000) on improving science teachers’ conceptions of NOS were not selected for this paper, yet the findings of this review were used as a reference for comparing previous studies with current studies. It should be also noted that during the selection of the articles the researcher did not find any intervention study that was published before 2000 and focused on improving science teachers’ conceptions of NOS, yet not included in Abd-El-Khalick and Lederman’s (2000) review. Finally, the researcher reviewed the
selected articles’ references to determine other studies that related to the topic. This resulted in 25 articles that met the criteria of being intervention studies that focused on elementary science teachers’ learning of NOS.

Research related to elementary science teachers’ learning of NOS can be conveniently divided into three related, but distinct, lines of research:

(a) The assessment of the effectiveness of attempts undertaken to promote elementary teachers’ learning of NOS (hereafter called “only teacher learning research”): Within this first line of research, science educators assessed just whether, and to what extent, the implemented intervention was effective in improving elementary science teachers’ conceptions of NOS. They just reported the changes (or lack thereof) in elementary teachers’ conceptions of NOS before and after receiving some kinds of NOS instruction.

(b) The investigation of why the impact of an intervention was not the same for all elementary science teachers and for all aspects of NOS (hereafter called “learning factors research”). Within this second line of research, science educators assessed not only how elementary science teachers’ conceptions of NOS were influenced as a result of their participations in the intervention, but also what kinds of factors and/or how particular factors influenced their learning of NOS.

(c) The assessment of the effectiveness of attempts in improving elementary science teachers’ understandings of NOS, their subsequent science teaching, and/or their students’ understandings of NOS (hereafter called “teacher learning, subsequent teaching, and/or subsequent student learning research”): Within this third line of research, science educators focused on what happens after elementary science teachers improved their
understandings of NOS. Therefore, their studies were guided by the following research question(s): To what extent did elementary science teachers reflect their gained understandings of NOS in their student teaching/classroom practices? What factors mediated the translation of elementary science teachers’ gained understandings of NOS into instructional planning and/or classroom practices? To what extent did elementary science teachers’ newly acquired understandings of NOS promote their students’ understandings of NOS?

**Only teacher learning research.** The intervention studies that focused only the changes (or lack hereof) in elementary science teachers’ conceptions of NOS were conducted by Abd-El-Khalick (2001), Akerson et al. (2000), Akerson et al. (2007), Celik and Bayrakceken (2012), Dass (2005), Koening et al. (2012), Matkins and Bell (2007), and Salter and Atkins (2013). These studies will be reviewed to gain more insights about effective NOS instruction for elementary science teachers as well as the research trends and gaps in the relevant literature.

*Lessons learned from only teacher learning research about effective NOS instruction.* The first lesson learned from intervention studies that focused only the changes in elementary science teachers’ conceptions of NOS is about which teaching approach seems to be more effective in improving conceptions of NOS. According to Abd-El-Khalick and Lederman (2000), earlier attempts adopted one of two approaches to teach NOS. The first approach, labeled as an *implicit* approach, is guided by an assumption that understanding of NOS is an affective learning outcome, and thus, it can be achieved through participating in process skill instruction, science content course, and ‘doing science’. The second approach, labeled as an *explicit* approach, considers
understanding of NOS as a cognitive learning outcome, and thus, such understanding can be achieved through intentional planning and drawing students’ attentions to specific aspects of NOS as in other science contents (Abd-El-Khalick & Lederman, 2000). With the review of the results of these studies, Abd-El-Khalick and Lederman (2000) concluded that explicit NOS instruction is relatively more effective than implicit NOS instruction in improving science teachers’ conceptions of NOS.

Based upon Abd-El-Khalick and Lederman’s (2000) definitions of explicit and implicit approaches explained in the previous paragraph, it can be said that the majority of the current attempts reviewed in this section generally used an *explicit* approach rather than an *implicit* approach to improve elementary science teachers’ conceptions of NOS (Abd-El-Khalick, 2001; Akerson et al., 2000; Akerson et al., 2007; Celik & Bayrakceken, 2012; Dass, 2005; Koenig et al., 2012). As in the review of Abd-El-Khalick and Lederman (2000), the findings of recent studies also showed that elementary teachers improved some of their NOS conceptions as a result of explicit NOS instruction. This consistent evidence in favor of the explicit approach implies its relative effectiveness in improving science teachers’ conceptions of NOS.

In earlier attempts that adopted the implicit approach to enhance science teachers’ NOS conception utilized science process instruction, science content coursework, and/or scientific inquiry activities without making explicit references to NOS (Abd-El-Khalick & Lederman, 2000). Unlike these earlier studies, more recent studies (Abd-El-Khalick, 2001; Akerson et al., 2007; Celik & Bayrakceken, 2012; Koenig et al., 2012; Matkins & Bell, 2007) continued to utilize science process instruction, science content coursework, and/or scientific inquiry activities, yet as a *context* to embed explicit NOS instruction.
The underlying assumption behind the integration of explicit NOS instruction in various science contents is to promote the translation of science teachers’ NOS conceptions into actual classroom practice. One of the advocates expresses this assumption as follows.

In our own research, preservice secondary science teachers often complained that NOS instruction and activities they experienced in science method courses did not help them address NOS instructionally during student teaching… It seemed that the different contexts within which our participant teachers learned about NOS (science method courses) and in which they were expected to apply their knowledge (science content courses) compromised their ability to translate their NOS conceptions into actual classroom practices (Abd-El-Khalick, 2001, pp. 215-216).

Such integration of the explicit NOS instruction was done in various science contexts, including a physics course for elementary teachers (Abd-El-Khalick, 2001), inquiry-based physics instruction in a summer workshop (Akerson, et al., 2007), social science based inquiry projects in the Science, Society and Technology course (Celik & Bayrakceken, 2012), scientific inquiry instruction in a science course (Koening et al., 2012), and a socioscientific issue of global climate change/ global warming in the science methods course (Matkins & Bell, 2007).

For instance, in their study Akerson and her colleagues (2007) developed a 2-week summer professional development to improve K-6 teachers’ conceptions of NOS. Their intervention consisted of two components: a morning section during which teachers learned physics through inquiry and an afternoon section during which teachers learned about pedagogy for teaching about physics, inquiry, and NOS through discussing the
inquiry activities in terms of NOS and its connection with inquiry teaching. In other words, the intervention attempted to merge inquiry based physics instruction with explicit-reflective NOS instruction. The findings of even such a short intervention showed that there were no completely unchanged teachers in terms of their conceptions of NOS. With that being said, the second lesson learned from this review is that current attempts to improve elementary science teachers’ conceptions of NOS suggest the use of both decontextualized (content-generic) and contextualized (content-embedded) activities in explicit NOS instruction, because it might help teachers to transfer their gained NOS conceptions into classroom practices.

The last lesson learned from only NOS learning studies is that researchers, who found positive changes in elementary science teachers’ conceptions of NOS, used oral or written reflection as an indispensable component of their explicit (decontextualized or contextualized) NOS instruction. In other words, it seems more appropriate to label these interventions as “explicit reflective” NOS instruction (Akerson et al., 2000) rather than just “explicit” NOS instruction as in the literature review of Abd-El-Khalick & Lederman (2000) and in the studies of Dass (2005) and Matkins and Bell (2007) reviewed for the purposes of the present study.

For instance, Matkins and Bell (2007) listed their research questions as “what is the effect of explicit, contextualized NOS instruction on preservice elementary teachers’ understandings of NOS, understandings of global climate change, and decision making on a socioscientific issue?” Even though the statement of research question did not include reflection, the descriptions of their intervention involved discussions made after various reading assignments or several contextualized activities. For instance, after the
participants did their reading assignments dealt with opposing views about reducing carbon dioxide emissions, they were asked to discuss about what these disagreements could tell us about science. In addition, following the fossil activity (a contextualized NOS activity, during which, in general, participants drew the rest of organism based on the given fossil fragments) the author facilitated a discussion about how the class activity was similar or different from the work of paleontologists. As evident in the two examples, reflection was a part of the explicit NOS instruction. In other words, Matkins and Bell (2007) actually investigated the effect of explicit and reflective contextualized NOS instruction on preservice elementary teachers’ understandings of NOS.

Research trends and gaps in the literature on only elementary teachers’ learning of NOS. The review of the intervention studies that examined just changes in elementary science teachers’ conceptions of NOS showed a shift in the assessment of NOS conceptions. In their critical review of the literature on the attempts to improve science teachers’ conceptions of NOS, Abd-El-Khalick and Lederman (2000) indicated that all of the reviewed studies, except the study of Shapiro (1996), utilized standardized paper-and-pencil instruments to assess participants’ conceptions of NOS. These studies were subjected to two main criticisms related to the validity of these instruments (Abd-El-Khalick & Lederman, 2000): (a) the problematic assumptions of these instruments that respondents and the instrument developers and/or researcher(s) would perceive and interpret an instrument’s items in the same manner and choose certain responses for the same reasons (Lederman & O’Malley, 1990) and these instruments usually enforce their developers’ NOS views and biases due to the response structure (Lederman et al., 1998), and (b) the substantive ‘adequacy’ of the used instruments (e.g., some instruments
developed around 1960s equated NOS with another construct such as scientific method). These criticisms regarding the use of paper-and-pencil instruments should have been taken into consideration by current attempts, because they, in contrary to previous attempts, employed qualitative approaches (Abd-El-Khalick, 2001; Akerson et al., 2000; Akerson et al., 2007; Matkins & Bell, 2007) or mixed approaches (Celik & Bayrakceken, 2012; Dass, 2005; Koening et al., 2012; Salter & Atkins, 2013) to assess participants’ conceptions of NOS prior to and at the conclusion of the intervention.

Consistent with earlier attempts (Abd-El-Khalick & Lederman, 2000), the majority of the current intervention studies were undertaken with preservice science teachers (Abd-El-Khalick, 2001; Akerson et al., 2000; Celik & Bayrakceken, 2012; Dass, 2005; Koening et al., 2012; Matkins & Bell, 2007; Salter & Atkins, 2013). The only intervention study with inservice science teachers was undertaken in the study of Akerson and her colleagues (2007). These researchers, however, noted that they plan to implement “follow-up interventions to support the change-in-views process started in the workshop” (p. 770). In other words, one cannot fully consider this study as an attempt that just focused on only NOS learning of elementary science teachers. Indeed, a closer look at the relevant literature indicated that these authors shared the results of their follow-up interventions in another study published in the same year (Akerson & Hanuscin, 2007). This implies that just learning research is of particular interest to those who have access to preservice elementary teachers. On the contrary, researchers who studied inservice elementary teachers did not just focus whether and/or to what extent participants changed their conceptions of NOS as a result of the intervention. In addition, they also studied how inservice elementary teachers translated their views into classroom practice.
In addition to the need of further research with inservice elementary science teachers, the aforementioned intervention studies that just focused tracking the changes in the conceptions of NOS also highlighted the importance of determining which component(s) of the given intervention were much more responsible for the detected changes. This is particularly important given that current studies generally combined explicit NOS instruction with various other forms of instruction such as science process skills (Matkins & Bell, 2007), scientific reasoning abilities (Koening et al., 2012), inquiry-based instruction (Akerson et al., 2007; Celik & Bayrakceken, 2012), history and/or philosophy of science (Dass, 2005), and project-based instruction (Celik & Bayrakceken, 2012). This need is acknowledged by Celik and Bayrakceken (2012) as one the main limitations of their study: “it [the study] was not designed to determine which component of the instruction; whether authentic inquiry experiences; explicit discussions; or the teaching approach pursued in course, affected PSTs’ [preservice science teachers’] NOS understandings” (p. 90).

The review of intervention studies that just examined NOS learning of elementary science teachers indicated that even though the same intervention was given to all participants, the gains were not consistent across participants or NOS aspects. For instance, following the explicit, reflective, activity based NOS instruction undergraduate students, compared to graduate students, showed relatively more gains in their views of NOS, except for the subjective, creative, and imaginative NOS aspects (Akerson et al., 2000). Furthermore, at the end of explicit, reflective activity based NOS instruction prospective science teachers changed more easily their mixed views, which were partially informed, than their naïve views toward informed views (Celik & Bayrakceken, 2012).
The findings of the two studies imply that like the contextual factors (e.g., the components of intervention discussed in the previous paragraph), individual differences (e.g., educational backgrounds and pre-instruction NOS conceptions) might be an important factor influencing learning of NOS. This, however, was not a main focus in the aforementioned studies. Rather, it is the focus of the second line of research on improving elementary science teachers’ conceptions of NOS, which is presented in the next section.

**Learning factors research.** The second line of research on elementary teachers’ learning of NOS is concerned with why the implementation of explicit NOS instruction does not result in improved NOS conceptions for all learners. Researchers in the field of science educations attempt to answer this question by following two distinct, but related lines of research. One group of researchers (Abd-El-Khalick & Akerson, 2004; McDonald, 2010) aim to identify the factors that might mediate the effectiveness of explicit NOS instruction, while the other group of researchers (Abd-El-Khalick & Akerson, 2009; Akerson et al., 2012; Akerson et al., 2006; Bell et al., 2011; Hanuscin, Akerson, & Phillipson-Mower, 2006; Matkins et al., 2002; Morrison et al., 2009; Shim et al., 2010) aim to explore the relationships between the particular factor(s) and improvement of the conceptions of NOS. Generally, the results of studies conducted by the former group of researchers give impetus to the latter group. The following section provides detailed information about the findings of these studies along with their implications for NOS research and NOS teaching.

**What factors mediate NOS learning of elementary science teachers?** There are only two intervention studies that aimed to explore this question (Abd-El-Khalick & Akerson, 2004; McDonald, 2010). The findings of these two studies provide empirical
evidence that various cognitive, motivational, contextual, task-specific, personal, and/or cultural factors might impede or facilitate elementary science teachers’ learning of NOS as in the learning of any subject matters. These learning factors described in depth in the following paragraphs.

The first study regarding the identification of learning factors mediating NOS learning was conducted by Abd-El-Khalick and Akerson (2004) with preservice elementary teachers in the context of elementary science methods course. To investigate this question, the researchers provided explicit reflective NOS instruction, yet paired it with instruction based on the view of learning as conceptual change advanced by Hewson, Beeth, and Thorley (1998). They argue that they replaced “conceptual ecology” with “learning ecology” to be sensitive to the various dimensions of learning that encompasses motivational, affective, contextual, social, and cultural factors in addition to cognitive ones. To identify factors in participants’ learning ecologies that might mediate the effectiveness of a given intervention on their NOS views, they closely followed six participants who showed differential growth in terms of their NOS views throughout the study: three of whom achieved only minimal growth while the other three achieved substantial growth in their views of NOS within the first five weeks of the course. The qualitative analysis of the focus group data indicated that the effectiveness of the given intervention was mediated by three factors that were motivational, cultural, and cognitive in nature.

The first mediating factor was motivational in nature. They found that those teachers who achieved substantial growth internalized the importance of teaching NOS in their future classrooms early in the course of intervention. In other words, the
participants’ perceptions of the importance and/or utility of learning and teaching NOS played a crucial role in facilitating favorable growth in their views of NOS.

The second factor was mostly cultural in nature. The participants’ religiously compatible worldviews interfered with learning about NOS when (a) they viewed science and religion as opposing rather than two distinct enterprises and/or (b) attempted to apply a dualistic ‘right/wrong’ perspective and the criteria of ‘credibility’, including the criterion of ‘Truth’, associated with religion to the realm of science.

The last factor was cognitive in nature. Those participants who achieved substantial gains in their views of NOS showed a deep processing orientation to learning. In particular, these participants (a) continually tried to seek and clarify the meaning of the key NOS terms as they negotiated ideas about NOS that were very different their own; (b) used these scientifically oriented meanings consistently across the tasks; and/or (c) monitored the changes in their NOS views using metacognitive strategies.

According to Abd-El-Khalick and Akerson (2004), one should consider these three factors tentative, because they were identified from examining just six students in the focus group. However, McDonald (2010) substantiates the importance of some of these factors in the development of NOS conceptions by identifying them with different groups of learners in another context. In particular, Abd-El-Khalick and Akerson studied with preservice elementary teachers who were provided an explicit reflective NOS instruction designed based on the conceptual change framework in the context of science methods course. McDonald, on the other hand, identified the factors that might mediate the development of NOS views by studying with preservice primary teachers in a science content course that incorporated explicit NOS instruction with argumentation instruction.
Like Abd-El-Khalick and Akerson (2004), in her study McDonald (2010) identified factors that addressed various dimensions of learning. McDonald labelled these factors mediating the learning of preservice teachers in the argumentation-based science content course under three dimensions: contextual, task-specific, and personal factors. Within the contextual dimension, she identified two factors that influenced the participants’ engagement in argumentation: (a) the context of argumentation (whether argumentation took place in a scientific or a socioscientific context) and (b) the mode of argumentation (whether argumentation was made orally or in written). Within the task-specific dimension, McDonald identified three factors, two of which promoted the participants’ engagement in argumentation (i.e., the inclusion of argumentation scaffolds, such as written assessment criteria that explicitly ask the participants to develop arguments and counterarguments, and the inclusion of alternative data and explanations) and one of which facilitated the development of the participants’ conceptions of NOS (i.e., the inclusion of epistemological probes, such as written or verbal prompts that drew the participants’ attention to relevant NOS aspects in the task). A closer look at the subcategories of the contextual and task-specific factors shows that all factors, except the inclusion of epistemological probes, have indirect effects on learning NOS through engaging the participants in argumentation. In other words, most of these factors are more specific to the context of argumentation, and thus, they could not be detected in the study of Abd-ElKhalick and Akerson (2004). The factor of epistemological probes, on the other hand, shows similarities with the reflective component of the NOS instruction undertaken in the study of Abd-ElKhalick and Akerson (2004), because the aim of these
two contextual factors was to draw participants’ attention to the relevant NOS aspects present in the instructional activity.

In addition to the aforementioned context and task-specific factors, McDonald (2010) also identified three personal factors that mediate the learning of NOS. The first personal factor was labeled as perceived previous knowledge on NOS: Those teachers, who perceived that they already knew about NOS, showed little or no substantial development in their NOS views because they did not initially recognize a need to change their pre-existing views of NOS. The second personal factor was the appreciation of the importance and utility value of NOS, which is very similar to Abd-El-Khalick and Akerson’s (2004) motivational factor involving their perceptions of the utility value and/or importance of learning and teaching NOS. Those teachers who perceived that the inclusion of NOS enhanced their learning of other course content showed substantial change in their views of NOS. The last personal factor was coded as durability and persistence of preexisting views or beliefs. At the conclusion of the intervention, it was observed that only teacher who continued to hold naïve or limited NOS views was the oldest participant in the study. He could not substantially change his views of NOS, that had developed over the duration of his school education as well as over nearly 30 years of post-school experiences, over the relatively short time frame of a single university course.

In summary, the findings of the aforementioned studies provide valuable insights for teacher educators and researchers in the field of science education by identifying various factors to be taken into consideration while designing and implementing instruction to improve elementary science teachers’ conceptions of NOS.
How do particular cognitive, motivational, and contextual factors influence the development of NOS understandings? The studies reviewed in this section investigate the relationships between elementary science teachers’ learning of NOS and particular cognitive, motivational, and contextual factors in addition to the assessment of the effectiveness of the given NOS instruction. It should be noted that even though cognitive, motivational, and contextual factors are presented separately below, it does not mean that they were independent from each other or they were studied in isolation or independently from the other factors.

**Cognitive factors.** Intervention studies that investigated the influences of cognitive factors on NOS learning of elementary science teachers focus on two factors: level of cognitive development (Akerson et al., 2006) and metacognition (Abd-El-Khalick & Akerson, 2009).

In their study, Akerson and her colleagues (2006) investigated the relationship between preservice elementary teachers’ cognitive developmental level and their retention of newly formed NOS views. They found that most of the preservice elementary teachers possessed inadequate views of all target aspects of at the outset of the study; however, they substantially improved their NOS views after one semester of an explicit reflective NOS instruction in the science methods course. When the researchers examined these teachers’ NOS views 5 months after instruction, they found that not all preservice teachers retained their improved NOS views. Preservice teachers at higher positions in terms of their cognitive development tended to retain all or most of their improved NOS views, while those at lower positions tended to revert to their earlier views on some or all of the NOS aspects. These findings suggest that the learner’s developmental level plays a
crucial role in predicting the retention of improved NOS views. As the authors claimed, these findings also provide implications for the inclusion of metacognitive teaching strategies in explicit NOS instruction to develop students’ understandings of NOS, because one of the distinctions between students at a lower and those at a higher level of cognitive development is the existence of metacognitive awareness of their ideas and understandings. This claim seems to be supported by the findings of Abd-El-Khalick and Akerson (2009), which are presented in the next section.

In another study, Abd-El-Khalick and Akerson (2009) aimed to test and substantiate the importance of deep processing learning orientation identified as an important cognitive factor in the development of NOS views in their previous study (Abd-El-Khalick & Akerson, 2004). They argued that those preservice teachers, who adopted a deep processing orientation, used self-monitoring metacognitive strategies as they negotiate NOS ideas different from their own NOS ideas. Therefore, in their latter study Abd-El-Khalick and Akerson (2009) assessed the possible relationships between enhanced metacognition and improved understanding of NOS.

To investigate the relationships, Abd-El-Khalick and Akerson (2009) employed a pretest-posttest, comparison group, quasi-experimental design using two sections of an elementary science methods course. Preservice teachers in both comparison and intervention groups were engaged with an explicit-reflective NOS instruction designed based on the view of learning as conceptual change framework that was found effective in their previous study with preservice elementary teachers (Abd-El-Khalick & Akerson, 2004). Additionally, preservice teachers in the intervention group received an instruction in, and use of, metacognitive strategies: (a) students constructed a concept map using a
given list of 14 NOS related concepts at the beginning of the course and then revisited and revised it several times during the remaining of the course; (b) investigated the development of NOS ideas of peer via conducting interviews and submitting a report documenting their analyses; and (c) responded to two case studies in an elementary classroom by developing lesson plans to help an elementary student and/or students improve their understanding of a specific aspect of NOS.

To assess the relationships between improved metacognition and enhanced NOS understandings, Abd-El-Khalick and Akerson (2009) utilized a parametric test and a nonparametric test in their study: the ANOVA test to assess the changes in metacognition gain scores between the intervention and comparison group and the nonparametric Chi-square test to assess the changes in the distribution of the pretest and posttest numbers of participants in the intervention and comparison groups who ascribed to naïve, partially informed, and informed NOS views. The ANOVA results revealed that preservice teachers in the intervention group who were engaged with the three metacognitive strategies improved their metacognitive awareness significantly greater than those in the comparison group who were not. Additionally, the Chi-square results showed that even though both the comparison and intervention groups held similar views of all five target NOS aspects at the outset of the study, the intervention group showed significantly more informed views of the empirical, tentative, theory-laden, and inferential NOS aspects than those of participants in the comparison group. The independent results of ANOVA and Chi-square test do not establish a causal link, yet they suggest that the development of improved understandings is related to the improved metacognitive awareness in the intervention group participants (Abd-El-Khalick & Akerson, 2009).
Motivational factors. Only one study (Akerson et al., 2012) was found in the literature that investigated the influence of a particular motivational factor on teachers’ development of NOS following the intervention. Even though the findings of this study provide evidence for possible relationships between motivational factors and NOS learning of teachers, further research studies are needed to substantiate these relationships, and thus, to get a better understanding of how to increase the effectiveness of interventions in improving elementary science teachers’ conceptions of NOS.

In their study, Akerson and her colleagues (2012) explored preservice early childhood teachers’ own cultural values, the cultural values they attributed to scientists, and the relationships between these values and their NOS views after participation in concurrent two courses based on explicit reflective instruction within conceptual change framework. Participating teachers completed the questionnaire on cultural values twice by considering themselves as well as by thinking how a scientist would respond before and after instruction. This allowed the researchers to explore the teachers’ cultural values and their perceptions of scientists’ cultural values in addition to assess the changes in these values over the course of the semester. In addition to the quantitative data, the researchers also collected qualitative data via the VNOS-B (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) instrument and the copies of the participants’ “Culture of a Scientists” notebooks.

The analyses of both quantitative and qualitative data revealed that participants perceived teachers and scientists as much more alike after participation in all parts of the courses. At the end of the semester, participants started to realize that both teachers and scientists value achievement, seek for security in their lives, and put others’ needs before
their own enjoyment. The findings also showed some relationships between understandings of NOS and perceived cultural gap between preservice teachers and scientists. Preservice teachers who reported fewer differences between their own cultural values and their perceptions of scientists’ cultural values held better conceptions of the sociocultural NOS aspect than those who reported more differences between cultural values they hold and those they perceive scientists hold. For instance, preservice teachers who strongly valued achievement and also thought that scientists strongly valued achievement held informed conceptions of the sociocultural NOS. In contrast, preservice teachers who personally valued achievement and did not think scientists valued achievement strongly held inadequate conceptions of the sociocultural NOS. This finding was explained by Akerson and her colleagues as students who perceive that scientists and teachers value achievement strongly may think that people in these jobs wish to achieve in their jobs, and thus, they showed concerted effort to have a better understanding of the course content, including conceptions of the sociocultural NOS.

Contextual factors. Compared to cognitive and motivational factors, researchers have given more attention to contextual factors and their relations to NOS learning of elementary science teachers. As contextual variables, some researchers explored the impacts of instructional approaches utilized to teach NOS (e.g., Abd-El-Khalick & Akerson, 2009; Bell et al., 2011; Matkins et al., 2002), while others investigated the influences of teachers’ academic backgrounds (e.g., Hanuscin et al., 2006; Morrison et al., 2009; Shim et al., 2010). The following paragraphs describe what these researchers found about the relationships between NOS learning and these two contextual factors.
There are three intervention studies that assessed the relative effectiveness of instructional approaches on elementary science teachers’ understandings of NOS (Abd-El-Khalick & Akerson, 2009; Bell et al., 2011; Matkins et al., 2002). All of these studies investigated the relationships between the improvement of NOS understandings and the implemented instructional approach in the context of elementary science methods course. In addition, they assessed which instructional approach was more effective in improving the conceptions of NOS by including a comparison group in their design of inquiry. This was not, however, the case for the majority of the studies reviewed for the purpose of this paper (Abd-El-Khalick, 2001; Akerson et al., 2000; Akerson et al., 2007; Celik & Bayrakceken, 2012; Dass, 2005; Koening et al., 2012; Matkins & Bell, 2007; Salter & Atkins, 2013) as well as the previous studies in the relevant literature that assessed the effectiveness of attempts undertaken to improve science teachers’ conceptions of NOS (Abd-El-Khalick & Lederman, 2000). Finally, the findings of the three studies (Abd-El-Khalick & Akerson, 2009; Bell et al., 2011; Matkins et al., 2002) suggest that some approaches utilized to teach NOS appeared to be more effective than others in improving preservice elementary science teachers’ conceptions of NOS as described in detail in the following paragraphs.

Two of the three studies, which assessed the relative effectiveness of instructional approaches, were conducted by Bell, Matkins, and their colleagues (Bell et al., 2011; Matkins et al., 2002). Both of these studies are the same, with the exception that more current study (Bell et al., 2011) includes quantitative analyses to support the qualitative findings regarding the changes in the six of seven target NOS aspects in the earlier study (Matkins et al., 2002). Both studies aimed to assess the impacts of explicit versus implicit
and decontextualized versus contextualized NOS instruction on preservice elementary teachers’ conceptions of NOS. The study data were collected over a period of four semesters in an elementary science methods course with a 2 x 2 matrix of nature of science and global climate change / global warming (GCC/GW) treatments: (a) explicit NOS, explicit GCC/GW; (b) explicit NOS, no GCC/GW; (c) implicit NOS, explicit GCC/GW; and (d) implicit NOS, no GCC/GW.

The qualitative analysis indicated substantial changes in the participants’ conceptions of NOS (i.e., the empirical, tentative, creative, subjective, inferential, and theory/law NOS) in the two explicit NOS treatment groups. In contrast, post-instruction responses of the participants in the two implicit NOS treatment groups remained largely unchanged from their pre-instruction responses. Quantitative findings also revealed significant differences in the participants’ pre-post views of the six target NOS aspects only in the explicit NOS treatments. However, they showed no significant difference whether explicit NOS instruction was embedded with or without GCC/GW. In summary, both quantitative and qualitative findings suggest that the use of explicit NOS instruction is more effective than implicit NOS instruction, while explicit NOS instruction without connecting it to the socioscientific issue of GCC/GW (decontextualized NOS instruction) is as effective as explicit NOS instruction integrated in GCC/GW instruction (contextualized NOS instruction) in improving teachers’ understandings of NOS.

In another study, Abd-El-Khalick and Akerson (2009) assessed the impact of training in, and use of, metacognitive strategies embedded in explicit reflective NOS instruction on prospective elementary teachers’ views of NOS by employing a pretest–post-test, comparison group, quasi-experimental design. Students in the intervention
section of the elementary science methods course received both metacognition and explicit-reflective NOS instruction, while those in the comparison section received only explicit-reflective NOS instruction. The nonparametric Chi-square tests showed that at the outset of the course students’ views of the six target NOS aspects (empirical, tentative, theory-laden, inferential, and creative NOS) were not significantly different between the intervention and comparison sections. At the conclusion of the course, however, students in the intervention section made statistically more gains in their views of the five NOS aspects than those in the comparison section. The only exception was that both groups did not statistically differ in terms of the pre-post gains in their views of the creative NOS aspect. Overall, these findings suggest that the integration of metacognitive strategies in explicit-NOS instruction increases its effectiveness in improving views of NOS.

Regarding the influence of academic backgrounds on conceptions of NOS, Lederman (2007) concluded in his comprehensive review that the teachers’ conceptions of NOS are not significantly related to their academic backgrounds (e.g., high school science credits, college science credits, specific science courses taken, grade-point average, mathematics grades, and years of teaching experience). More recent studies (Hanuscin et al., 2006; Shim et al., 2010), however, have continued to investigate the effects of teachers’ academic backgrounds, including undergraduate or graduate major, teaching experience, and the level of science taught, on their learning of NOS.

In their study, Hanuscin et al. (2006) investigated NOS views of undergraduate teaching assistants prior to, and after the completion of, the professional development. The participants of this study consisted of nine undergraduate teaching assistants, 3 of
which earned education major and the remaining had physics majors. The analysis indicated that all participants changed their views about at least one NOS aspect. The comparison of these changes in NOS views revealed that unlike undergraduate teaching assistants with education majors, those with physics majors were able to use historical examples or examples from their research experience to illustrate their understanding of the targeted NOS aspects at the conclusion of the intervention. This finding suggests that having undergraduate major in scientific disciplines in addition to education majors might foster teachers’ learning of NOS because such teachers would have different resources (e.g., knowledge or experience in these scientific disciplines) that can be capitalized in the process of learning new information related to science such as NOS.

In another study Morrison et al. (2009) also found the impact of having an undergraduate or graduate major in science on teachers’ learning of NOS. In particular, elementary and middle school teachers who did not have an undergraduate or graduate major in science showed more growth in their views of NOS than secondary teachers who hold a science degree. At first glance, this finding seems to be contradictory with the one documented in the study of Hanuscin et al. (2006). In reality, this was not the case, because it would be unrealistic to expect secondary teachers to show significant changes in their NOS views when they already started the course with more solid understanding of NOS than elementary and middle school teachers. In other words, teachers who held a science degree, compared to those who did not, entered the projects with NOS views that generally showed alignment with the accepted beliefs about NOS.
In summary, Hanuscin et al. (2006) and Morrison et al. (2009) identified the undergraduate or graduate major as an important academic background variable that plays a crucial role in the acquisition of NOS understanding.

In another study, Shim et al. (2010) explored the impact of teaching experience on views of NOS in two ways. First, they checked whether student teachers held similar NOS views with practicing teachers before and after a semester of methods course focusing on inquiry-based science instruction. They found that at the beginning of the course preservice and inservice teachers did not have different NOS views. Following implicit NOS instruction, however, preservice teachers held significantly different NOS views than inservice teachers. Second, they assessed the differences in NOS views between inservice teachers who assumed to receive implicit NOS instruction due to their participation in professional development programs in the use and science content of inquiry-based kits and those who did not use kit-based science curriculum in their schools. The findings showed no significant differences in the NOS views among inservice teachers with different teaching experience using science kits. The authors explained these two findings as inquiry-based science instruction might help preservice teachers improve their NOS views, but inservice teachers seems to need more explicit exposure to the more contemporary NOS views in their inquiry-based professional development experiences.

Different from Shim et al., (2010) who explored whether preservice teachers may differ from inservice teachers in their views about NOS, Morrison et al. (2009) investigated whether elementary and secondary teachers may benefit from a professional development experience differentially due to the differences in science research
experiences and past instruction. The findings showed that secondary teachers who had undergraduate or graduate degrees in science and had taught high school science did not significantly change their NOS views. Rather they reaffirmed or validated their views of NOS and gained new insights about teaching their students about NOS from their job shadowing experience or an interview with a scientist. On the other hand, elementary and middle school teachers who did not hold a science degree or any personal interactions with scientists in the past found interviewing, job shadowing, or simply having informal lunch time conservations with scientists helped them improve their NOS views.

In summary, the findings of Morrison et al. (2009) and Shim et al. (2010) imply that NOS learning may vary with respect to whether participants are preservice or inservice teachers and whether participants teach in elementary or secondary schools.

**Teacher learning, subsequent teaching, and/or subsequent student learning research.** The third line of research is concerned with not only elementary science teachers’ learning of NOS but also their teaching of NOS (Akerson & Abd-El-Khalick, 2003; Akerson et al., 2009a; Akerson & Hanuscin, 2007; Akerson et al., 2009b; Cullen et al., 2010; Donnelly & Argyle, 2011; Posnanski, 2010). Among these seven studies, only two of them (Akerson & Hanuscin, 2007; Cullen et al., 2010) followed up NOS learning of these teachers’ students. All of the intervention studies within this line of research used practicing teachers as a sample, especially K-6 teachers, and mostly conducted by Akerson and her colleagues. The following section provides detailed information about the findings of these studies, along with their implications for future professional development programs and future research on elementary science teachers’ learning of NOS.
Is there a direct relationship between elementary science teachers’ newly gained understandings of NOS and their classroom practices? Consistent with the literature reviews of Lederman (1992, 2007), the findings of current intervention studies investigating what happens after teachers learned NOS suggest that teachers do not always reflect their improved understandings in their classroom practices. In one of her studies, Akerson and her colleague (Akerson & Abd-El-Khalick, 2003) employed a case study approach to explore in depth the relationships between teachers’ understandings of NOS and their classroom practices. At the outset of the study, authors aimed to investigate whether having informed views of NOS and intention to teach about NOS was sufficient for an experienced fourth grade teacher to effectively teach about NOS to her own students. As the study progressed, the researchers had to shift the focus of their study to what specific supports the teacher were needed to address NOS instructionally, because the teacher requested help from the researchers in order to make explicit the three NOS aspects she targeted in her teaching. They found that after the lead author’s socially mediated supports at the personal level by helping the teacher activate her newly acquired and tacit NOS views and at the professional level by modeling how to address NOS explicitly in her classroom, the teacher was able to translate her views and intentions into explicit NOS instruction.

Even though improving teachers’ understandings of NOS do not always lead to effective NOS instruction in their classrooms, it would be unrealistic to expect teachers to teach about NOS without knowing the content itself. In other words, there is a direct relationship between teachers’ content knowledge about NOS and their classroom practices when teachers held inadequate or naïve understandings of NOS. This claim
seems to be supported by the findings of the following two studies (Akerson et al., 2009a; Akerson et al., 2009b).

In one of these two studies, Akerson and her colleagues (Akerson et al., 2009a) assessed the influence of a community of practice professional development program on three elementary teachers’ views of NOS and their teaching practices. The findings showed that the professional development influenced individual teachers’ NOS views and their teaching practices differentially. In particular, the marginalized member in the community struggled with her gained NOS views and was not able to integrate them into her classroom. The leader teacher in the community, however, possessed informed and cohesive NOS views and explicitly integrated them in her classroom practice in all science lessons.

In the second study, Akerson and her colleagues (Akerson et al., 2009b) assessed the impact of a K-6 professional development program that emphasized NOS and scientific inquiry within the theme of scientific modeling on teachers’ views of NOS. At the end of an intensive 2-week summer workshop, the participating teachers developed a life science unit to be taught in the subsequent school year. The teachers continued to experience inquiry-based life science instruction during the school year workshops and they were provided classroom support when they requested. The analysis showed that after the summer workshop one of the teachers who did not improve much his views of NOS did not include NOS into not only his lesson plans but also his classroom. On the contrary, the teacher who improved the most in her NOS views included NOS as an objective in her lesson plans, yet NOS was absent during her classroom practices.
In summary, consistent with previous studies, the aforementioned current studies highlight that having informed understandings of NOS is necessary, but not sufficient for teachers to effectively teach about NOS to their own students (Lederman, 1992). As in the learning of NOS, there seems to be various cognitive, motivational, social, cultural, personal, and/or contextual factors that explain the discrepancies between teachers’ understandings of NOS and their classroom practices. The following section provides more information about how we can promote changes in teachers’ instructional practices to help them improve their own students’ understandings of NOS by highlighting various factors to be taken into consideration in the development and implementation of the professional development programs.

What kinds of factors, and how these factors, influence elementary science teachers’ translation of their conceptions of NOS into their classroom practices? The factors that mediate the relationships between elementary science teachers’ understanding of NOS and their classroom practices can be combined under three broad categories: cognitive, motivational, and contextual. Factors identified in each category are explained in the following three subsections. It should be noted that cognitive, motivational, and contextual factors are presented separately below, though it does not mean that they were independent from each other or they were studied in isolation or independently from the other factors.

**Cognitive factors.** In addition to teachers’ content knowledge regarding NOS, described earlier in this paper, two intervention studies (Akerson & Abd-El-Khalick, 2003; Akerson et al., 2009a) explicated the importance of teachers’ science content knowledge in the translation of their NOS views into classroom practices. For instance,
during one of her classroom observations Akerson realized that the fourth grade teacher did not make any explicit references to relevant NOS aspects, though the lesson on drawing a model of the inside of the earth was a prime opportunity to help students think about the empirical and inferential NOS (Akerson & Abd-El-Khalick, 2003). Like Akerson, the observed teacher also recognized the missed opportunity, because during the recess she shared her concern about how to teach about NOS without knowing exactly what kinds of evidence scientists use to create the model of the earth’s inside. In other words, even though the teacher possessed informed views of the empirical and inferential NOS, she could not help her students to think about NOS because of her lack of content knowledge in earth science.

**Motivational factors.** In addition to adequate NOS and science content knowledge, the intervention studies that focused science teachers’ learning of NOS and their subsequent NOS teaching (Akerson et al., 2009a; Donnelly & Argyle, 2011; Posnanski, 2010) also suggest that teachers should have necessary motivation to teach about NOS in order to help their students improve their understandings of NOS. For instance, in her study Posnanski (2010) found that some K-8 teachers raised doubts about the ability or need to incorporate NOS in their classrooms as such some believed that NOS was not overtly emphasized in their districts standards and exams and that special effort was needed to incorporate NOS into their classrooms. In addition to the importance of teaching NOS in general, teachers seemed to believe that some aspects of NOS were more important or appropriate to teach for their students, because in contrary to the empirical and creative NOS aspects, the theory/law aspect of NOS was absent not only during their instruction but also in their action research plans. These findings lead the
author to conclude that teachers’ beliefs such as their self-efficacy beliefs and outcome expectancy about learning and teaching all, or some, aspects of NOS might mediate translation of their NOS views into classroom practice.

**Contextual factors.** Even though teachers themselves are cognitively and motivationally ready to teach about NOS in their classroom, they might still not promote their students’ understandings of NOS if their work environment is not supportive for effective NOS teaching. The possible impact of such contextual factors was observed in the findings of two intervention studies that examined the impact of a professional development program on inservice teachers’ views NOS views and NOS teaching practice (Akerson et al., 2009a; Donnelly & Argyle, 2011). For instance, in their study Akerson and her colleagues (Akerson et al., 2009a) found that among their three participants only one did not include NOS in her classroom, though she made changes in her NOS views. The lack of changes in this teacher’s classroom practices might be explained by pressure she felt in her school about teaching the notion of the scientific method, which was challenged over the course of the professional development program. Another reason might be that the teacher was in a district whose superintendent did not support her participation by the end of the professional development program. In the second study, Donnelly and Argyle (2011) found significant differences in the number of NOS activities used or planned to use across urban, suburban, and rural school teachers. In particular, suburban and rural teachers were more likely to adopt the NOS activities than urban teachers. Authors claimed that this discrepancy might be due to the fact that urban teachers were mostly from districts at risk of not meeting No Child Left Behind’s adequate yearly progress benchmarks. In other words, the districts where rural teachers
worked might have different needs than urban and suburban districts. It should be noted that the findings of Donnelly and Argyle’s (2011) study should be interpreted with caution because they relied exclusively on teachers’ self-reporting of their classroom practices without classroom observations and the study had relatively small sample size.

**What lessons learned about effective NOS instruction for elementary science teachers?** Unlike the intervention studies within the first line of research (i.e., only teacher learning section) that mainly used preservice elementary teachers as a sample, all studies within the third line of research (i.e., teacher learning, subsequent teaching, and/or subsequent student learning research) used inservice teachers as a sample. The comparison of the nature and components of NOS instruction, given for preservice and inservice elementary teachers in these two lines of research, shows both similarities and differences. The first commonality is about the effectiveness of explicit reflective NOS instruction in improving elementary science teachers’ understandings of NOS. The second commonality is concerned with the use of both decontextualized and contextualized activities to help elementary science teachers translate their NOS understandings into their classroom practices. With that being said, future professional development programs should follow the trend of providing explicit reflective NOS instruction that include both decontextualized and contextualized activities to promote elementary preservice and inservice science teachers’ development of conceptions of NOS.

One of the differences between these two lines of research is that with the exception of one study (Donnelly & Argyle, 2011), all intervention studies that focused on inservice teachers’ learning of NOS and their subsequent classroom teaching did not
limit the duration of their intervention to a single semester. Rather, they preferred to engage inservice elementary teachers in longer explicit-reflective NOS instruction, generally a summer workshop plus several workshops during the subsequent school year. This deemed important for teachers to internalize their newly acquired conceptions of NOS so that they can convey them into their classroom practices.

The second difference is the inclusion of NOS teaching as a component of professional development programs (Akerson et al., 2009a; Akerson & Hanuscin, 2007; Akerson et al., 2009b; Cullen et al., 2010; Posnanski, 2010) to help inservice science teachers apply their newly acquired knowledge of NOS and/or NOS teaching approaches in their classrooms. This suggests that an effective inservice program should provide teachers opportunities to practice new ideas and skills (Henriques, 1998). Teaching these newly acquired understandings of NOS in their own classroom might help teachers to improve their understandings of NOS (Akerson & Abd-El-Khalick, 2003) and their beliefs about teaching NOS (Donnelly & Argyle, 2011) when teachers observed measurable growth in their own students’ learning outcomes (Guskey, 1985, 1986, 2002).

The third difference is about the amount of content to be covered in the intervention. The intervention studies within the first line of research did not pay attention to which elements of the intervention were most effective for improving participants’ conceptions of NOS. However, some of the intervention studies within the third line of research (Donnelly & Argyle, 2011; Posnanski, 2010) explicitly asked their participants the strengths and/or weaknesses of the inservice programs at the conclusion of their studies. The analyses of these program evaluation documents revealed that some teachers perceived the content of the programs too extensive. Inservice teachers
suggested future NOS professional development endeavors to devote considerable time to NOS instruction (Donnelly & Argyle, 2011) and to take the grade level taught by teachers into consideration in deciding the depth of the content (Posnanski, 2010). The first suggestion seems to be valid for other studies as well (Akerson et al., 2009a; Akerson et al., 2009b; Cullen et al., 2010), because inservice teachers were expected to learn simultaneously not only NOS but also scientific modeling, scientific inquiry, content in various science domains (e.g., physical science, life science content, earth science) and/or how to conduct action research in their classrooms. The second suggestion also seems to be supported when taking a closer look at the range of grade levels the professional development programs were provided (generally given for K-6 teachers in a single intervention). Considering that balancing the depth of content to be covered for kindergarten teachers and sixth grade teachers is very difficult, it would be logical to claim that future professional development programs should be designed for a specific grade level or a narrow grade level band.

**What are some implications for future research on elementary science teachers’ learning of NOS?** Even though teaching was included in the professional development programs within the third line of research, the main focus in these studies was to determine to what extent teachers reflected their understandings in their classroom. Only two of these studies (Akerson & Abd-El-Khalick, 2003; Posnanski, 2010) discussed the possibility of an increase in teachers’ conceptions of NOS after teaching NOS in their own classrooms. This is, however, a tentative conclusion to be substantiated in future research because of the following reasons.
First, Posnanski (2010) concluded that the action research plan implementation might have influenced teachers’ understandings of NOS by just looking at responses on the post-program evaluation surveys and interviews: Majority of the participants (i.e., 16 out of 22 K-8 teachers) identified action research plan implementation as one of the program strengths because it provided means to (a) reflect on their science teaching, (b) make connections between their professional development experience and the classroom, and (c) impact their science instruction. Furthermore, Posnanski relied on self-report data in terms of the impact of action research plan implementation on teachers’ understandings of NOS. The change in the teachers’ understandings of NOS from pre- to post-NOS surveys might have resulted from their engagement in explicit-reflective NOS instruction or inquiry-based lessons on earth science, life science, and physical science other than their use of action plans in their classroom.

Second, Akerson and Abd-El-Khalick (2003) focused on NOS teaching of a single teacher to identify what specific supports the teacher needed to make NOS explicit in her teaching. Different from Posnanski (2010), they assessed this fourth grade teacher’s understandings of NOS before and after teaching NOS in her classroom. The analysis showed that following NOS teaching experience the participant sustained her improved understanding of the empirical NOS and her naïve understanding of the theory/law NOS. Even though the participant improved her understandings of the inferential, tentative, creative, subjective, and sociocultural NOS, Akerson and Abd-El-Khalick (2003) claimed that refinements in the participant’s understandings of NOS were relatively more prominent in the case of aspects she targeted in her teaching (i.e., inferential, tentative, and creative NOS). This seemed to suggest that teaching is another
way to learn NOS; however, the researchers did not ask explicitly to the participant whether she perceived this impact or not. The change the researchers perceived might be something the participant already knew, yet could not externalize in her pre-teaching NOS survey and interview. This means that in future studies researchers should validate the identified impact of teaching on improving understandings of NOS with the study participants.

In addition to the investigation of the impact of teaching on improving elementary science teachers’ understandings of NOS, the review of intervention studies has highlighted the need for professional development programs that promote elementary science teachers’ motivation to teach about NOS. This gap seems to appear when the second and third lines of research were compared. Both studies that explored what kinds of factors might mediate NOS learning and teaching of elementary science teachers (Abd-El-Khalick & Akerson, 2004; Akerson et al., 2009a; Donnelly & Argyle, 2011; McDonald, 2010; Posnanski, 2010) commonly identified teachers’ motivation to teach about NOS (i.e., teacher beliefs about the importance and/or appropriateness of teaching NOS). In addition to these two lines of research that converged with possible role of teachers’ motivation to teach about NOS in their learning and teaching NOS, many studies with elementary and secondary teachers provided evidence that teachers do not consider NOS as one of the most valuable instructional outcomes (Abd-El-Khalick et al., 1998; Duschl & Wright, 1989; Gess-Newsome & Lederman, 1993; Lederman, 1999; Lederman, Gess-Newsome, & Latz, 1994; Sahin & Koksal, 2010) or that they cast doubt on their students’ ability to learn all, or some, aspects of NOS (Akerson & Abd-El-Khalick, 2003; Lederman, 1999; Sweeney, 2010). Unfortunately, no intervention study
was found in the relevant literature that focused how to change teacher beliefs about
importance and appropriateness of teaching all, or some, aspects of NOS and their
relationships with learning of these aspects of NOS.

**Research on Conceptual Change**

Researchers and educators in the discipline of science education seek ways to
enhance our understanding of what science learning is and how science learning takes
place (Southerland et al., 2006). According to many science education policy documents,
understanding of NOS constitutes one of the crucial components of science learning
learning, however, simply assessed changes in learners’ conceptions of NOS without
providing a mechanism explaining these changes (Lederman, 2007). In this respect, the
present study attempted to further make sense of the process of learning science,
particularly the process of learning NOS, in the minds of teachers by investigating not
only the changes in elementary science teachers’ conceptions of NOS with respect to the
nine target aspects but also their interactions with the components of a one-year
professional development program.

In science education many researchers who are investigating learning outcomes
(in this case, conceptions of NOS) are interested in the view of learning as conceptual
change, namely how individual conceptions change over time in a way that they become
more consistent with the scientifically accepted conceptions (Treagust & Duit, 2009).
Moreover, constructivism, with its origin in cognitive science, is listed in
chemistry/science education as a dominant and useful theoretical framework for those
“who is seeking to understanding alternative conceptions, conceptual changes over time,
or the construction of knowledge” (Ferguson, 2007, p. 43). Therefore, this study draws upon conceptual change models along with constructivism that has been used in explaining the process of learning science.

**A brief history of conceptual change research and constructivism.** Science educators no longer agree with the notion that students enter science classes as empty vessels to be filled up with the scientific knowledge (Bell & Gilbert, 1994). Rather, they realized since the 1970s that students bring with them to science classes certain conceptions that are generally not consistent with those of scientists or targets of instruction to be taught in science classrooms (Carey, 2000; Treagust & Duit, 2009; Vosniadou, 1999). In the history of conceptual change research, such conceptions were given different names (e.g., misconceptions or alternative conceptions) by different researchers based on their philosophical orientation (Treagust & Duit, 2009). For more than three decades, researchers have investigated these pre-instructional conceptions in different domains of science (Treagust & Duit, 2009) in addition to NOS (Lederman, 1992, 2007). The results of these studies have well-documented that misconceptions are often firmly held and difficult to extinguish even given instruction designed to alter those ideas (Akerson et al., 2009a; Carey, 2000; McDonald, 2010; Treagust & Duit, 2009; Vosniadou, 1999). Although most of these researchers had been influenced by Piaget’s constructivist epistemology (Vosniadou, 1999), they realized the need for shifting from a stage-dependent view of learning science (e.g., the elementary school child is concrete thinker not capable of abstract reasoning) as a response to the accumulation of empirical evidence indicating students can do more than what it was thought before (e.g., the elementary school child, just like the scientist or another adult, is a theory-bound thinker
and capable of being engaged at a theoretical level, yet with some difficulties) (Carey, 2000).

According to Vosniadou (1999), the conceptual change model proposed by Posner, Strike, Hewson, and Gertzog (1982) is one of the products of the search for a new theoretical framework to conceptualize the learning of science because this group of science educators used the history and philosophy of science as a major source of their hypothesis to explain how concepts change. Even though these science educators also used Piaget’s words such as assimilation and accommodation in their attempt to describe the process of conceptual change, they explicitly noted that they did not intend any commitment to his theory (Posner et al., 1982). In their original conceptual change model, Posner et al. drew a parallel between the restructuring process experienced by science learners and Kuhn’s process of scientific revolutions in the scientific community. According to this view of learning, a full blown conceptual change in the minds of learners is analogous to scientific revolutions in the history of science. If the learners find the new conception more intelligible (understandable), plausible (reliable), and fruitful (worthwhile) than the competing, preexisting conception then they replace the competing, preexisting conception with the new conception through the process of rational comparison (Posner et al., 1982).

After a decade, Posner and his colleague (Strike & Posner, 1992) revised their theory of conceptual change in line with various criticisms subjected to their initial formulation of the theory. One of the paramount modifications, particular interest of this study, was concerning the inclusion of a wider range of factors to describe the process of conceptual change. Posner and Strike acknowledged that relying heavily on philosophy
of science in their initial formulation of the theory of conceptual change might lead them to conceptualize learning as overly rational and to downplay the influences of motives, goals, social, and contextual factors on conceptual change. Therefore, in addition to epistemological factors suggested by the history and philosophy of science, in their revisionist theory Posner and Strike suggested the inclusion of social and motivational factors that might play an active role in the process of conceptual change.

Interestingly enough, around the same time researchers in the history of constructivism (O’Loughlin, 1992; Solomon, 1987) also became more interested in social nature of meaning making and proposed social constructivism as an alternative to the personal constructivism of Piaget whose primary focus is meaning making within the individual. By merging these two extreme perspectives of constructivism, Driver, Asoko, Leach, Mortimer, and Scott (1994) suggested that learning of science involves both individual and social processes. With that being said, both research on conceptual change and constructivism suggest the need for interpreting science learning from a multidimensional framework in early 1990s.

In 1993, with the article “Beyond Cold Conceptual Change: The Role of Motivational Beliefs and Classroom Contextual Factors in the Process of Conceptual Change” Pintrich, Marx, and Boyle attempted to fill the aforementioned gap in the field of conceptual change because previous research focused primarily on the influence of cognitive factors (e.g., students’ existing knowledge and misconceptions) on change, developmental changes in the knowledge representation of young learners, or the pedagogy for conceptual change (Sinatra, 2005). However, Pintrich and his colleagues (1993) included both irrational factors such as affective, motivational, and situational
factors and rational factors in their attempt to describe the process of conceptual change. They argued that students’ motivational beliefs about themselves as learners and the individuals in the learning environment might influence (or sometimes determine) whether change occurs. Because of not taking into consideration the variables other than student cognition, Pintrich and his colleagues labeled previous models of conceptual change as “cold” or overly rational. It is notable that the conceptual change model proposed by Pintrich and his colleagues was one of the seminal works in the field because it started a “warming trend” in conceptual change research and inspired the development of new conceptual change models such as Dole and Sinatra’s (1998) Cognitive Reconstruction of Knowledge Model and Gregoire’s (2003) Cognitive-Affective Model of Conceptual Change (Sinatra, 2005).

Given that the review of empirical studies on elementary science teachers’ learning of NOS (discussed earlier in this document) documented various cognitive, motivational, and contextual factors mediating the changes in learners’ conceptions of NOS, Pintrich and his colleagues (1993)’s multidimensional model of conceptual change (which includes not only “cold” rational cognition but also “hot” components of motivational beliefs and the situated nature of learning in classroom context) was selected as the most appropriate theoretical framework to ground this study. Therefore, more space is allocated to provide more in-depth and richer pictures of how motivational beliefs might facilitate conceptual change, how motivational beliefs might influence learning, and how the classroom context might mediate the relations between motivational beliefs and cognition.
The “hot” model of conceptual change. Two assumptions guided Pintrich and his colleagues’ (Pintrich et al., 1993) hot model of conceptual change learning. First, the four basic conditions of conceptual change (dissatisfaction, understanding, plausibility, and fruitfulness), proposed by Posner and his colleagues (Posner et al., 1982), are influenced by a variety of cognitive factors. They hypothesized that these cognitive factors include directing selective attention to new information, activation of prior knowledge, the use of deeper cognitive processing strategies such as elaboration via paraphrasing and summarizing and organization via concept mapping and networking, finding or becoming aware of problems and having ability of solving these problems, the use of various metacognitive evaluation and control strategies such as reflection on and self-questioning old beliefs, and the use of volitional and self-control strategies such as effort and persistence management.

Second, Pintrich et al (1993) assumed that these various cognitive factors depend on students’ motivational beliefs, which are created, shaped, and constrained by various features of the classroom context. Using a variety of theoretical models from a social cognitive perspective on motivation, Pintrich et al organized these motivational beliefs around two general factors: students’ beliefs about their reasons for choosing to do a task (the value components) and their beliefs about their capability to perform a task (the outcome expectancy components). Among these two factors, the value components of motivation were particular interest of this study because the participating teachers’ perception of to what extent each aspect of NOS targeted in the professional development program is developmentally appropriate and important for their own students might be a reason for them to learn NOS aspects differentially. Teachers might choose to do
professional development activities that address NOS aspects they perceived appropriate and/or important to teach for their own students. In other words, teachers’ beliefs about the developmental appropriateness and importance of teaching NOS were considered as a part of the value they ascribe to learn NOS. Thus, the following paragraphs provide more information about the relationships between the value components of motivation and conceptual change in the classroom context.

According to Pintrich et al (1993), the value components of motivation include goal orientation, interest, and importance. Goals, which are “self-constructed ‘theories’ about what it means to learn and what it means to succeed in a context”, function as a resource or constraint for conceptual change (Pintrich, 1999, p. 35). In particular, when students adopt a mastery goal orientation (which focuses on learning, understanding and mastering the task) rather than a performance orientation (which focuses on obtaining a good grade or besting others), they will be more likely to engage in deeper cognitive processing that facilitates the potential for conceptual change (Pintrich, 1999; Pintrich et al., 1993). Although students’ adoption of a mastery goal orientation seems to be positively related to the level of their cognitive engagement, individual students might prefer to adopt a mastery or performance goal orientation based on several features of classroom context such as the nature of the tasks (whether and/or to what extent individual students see the task as challenging, meaningful, and authentic), the authority structure in classrooms (whether and/or to what extent individual students have choice or control over their activities in classrooms), and evaluation procedures in classrooms (whether and/or to what extent individual students perceive that their academic
performance is evaluated based on competition, social comparison, and external rewards) (Pintrich, 1999; Pintrich et al., 1993).

In addition to goals for learning, students’ goals about knowledge as an object (which refer to epistemic motivation) might influence their cognitive engagement and potential for conceptual change (Pintrich et al., 1993). Epistemic motivation consists of two dimensions: (a) seeking or avoiding closure (an individual’s attempts to bring an end to the hypothesis development and testing process via finding an answer to a question or an individual’s attempts to continue the hypothesis development and testing process via delaying an answer to a question, respectively) and (b) specificity or nonspecificity (the individual’s seeking one answer or being satisfied with any answer, respectively). As in the learning goals, students might activate different epistemic motivations with respect to structural characteristics of classrooms. Classroom activities or instruction that do not set time constrains to finish the academic work and stress the need for finding definite answers in the products of academic work would be more likely to facilitate cognitive activity and conceptual change.

Students’ interest and value beliefs, like their goals and goal orientation beliefs, are related to their reasons for engaging in tasks (Pintrich et al., 1993). Unlike more cognitive and situational representations of goals, students’ interest and value beliefs are more affective or attitudinal in nature. Thus, they might be more stable and personal. In other words, Pintrich and his colleagues were more interested in personal interest and value beliefs that individual students bring to different tasks. Moreover, they proposed that three general interest or value beliefs interact with task features to support learning. These interest and value beliefs include *interest* (the student’s general attitude towards
the content or task), utility value (the student’s instrumental judgment about the potential usefulness of the content or task for the achievement of some goals), and importance (the student’s perception of the significance and worth of the task or content to the individual). These different interest and value beliefs were assumed to be related to learning due to their influences on the types of motivational goal orientation students can adopt in classroom, the quality of their cognitive engagement, their attention, their activation of appropriate knowledge, their effort and persistence management strategies (Pintrich et al., 1993).

Among the value components of motivation, it seems that elementary teachers’ beliefs about developmental appropriateness and importance of teaching NOS aspects are directly related to the construct of personal interest and value beliefs while indirectly related to the construct of goal orientations. In particular, those teachers who believe that teaching certain NOS aspects are more appropriate and/or important than teaching other NOS aspects are more likely to bring different interest and value beliefs to professional development activities. Therefore, they might tend to show more attention to, or cognitively engage in, activities that address NOS aspects they deemed more appropriate and important for their own students. On the other hand, their different interest and value beliefs might induce the adoption of different types of goal orientation in different professional development activities, which would in turn influence the quality of their cognitive engagement and then their learning of NOS aspects.

**Research on Effective Professional Development Programs**

After surveying a nationally representative probability sample of more than 1,000 teachers, mostly in mathematics and science, Birman and her colleagues (Birman,
Desimore, Porter, & Garet, 2000) identified three structural features that set the context for professional development (PD) (form, duration, and participation) and three core features that characterize the process of learning during a PD program (content focus, active learning, and coherence). The relevant literature is reviewed in terms of these six features to gain insights about how an effective PD program should look like.

**Structural features of effective professional development.** According to Birman and her colleagues (Birman et al., 2000), one of the structural features of a PD program is its form, which is concerning about whether the PD program was structured in a traditional format (e.g., workshop or conference) vs. in a reform format (e.g., study group or teacher network). In their studies, Birman and her colleagues (Birman et al., 2000; Garet, Porter, Desimone, Birman, & Yoon, 2001) provided empirical evidence that a traditional PD program can be as effective as a reform PD program as long as it has appropriate duration, subject-matter content, active learning, and coherence. In other words, what really matters is not the form of PD, rather the core characteristics of the PD activities.

With the acknowledgement of the primary role of the characteristics of activities in teacher development, the present study structured the PD program of elementary science teachers using a reform format rather than traditional approaches such as one-shot workshops or institutes. Given that the extent to which a PD program impacts teacher knowledge and practices is enhanced by the extent to which that program also strengthens the *professional community* in the school (Ingvarson, Meiers, & Beavis, 2005), in the recruitment of the study participants the mission of this PD program was explicated as to form a professional community. In this community, teachers were
empowered as leaders (they decided when to meet and how to teach), contributors (they had expertise regarding what content is developmentally appropriate and important to teach to elementary students), and supporting one another. In addition to teachers, the professor and the graduate student were also be the members of this community by sharing their experience about NOS and NOS teaching while being vulnerable to criticism. Finally, the students of participating teachers were members of this community as learners and contributors, because enduring change in teachers’ beliefs and attitudes comes after teachers begin using a new practice successfully and see changes in student learning (Guskey, 1985, 1986, 2002). In other words, as an integral and key part of the PD, participants practiced teaching NOS in their own classrooms. Such teaching experience gave the participating elementary teachers an opportunity to change their beliefs about developmental appropriateness and importance of teaching NOS aspects.

*Duration* is another structural characteristic of a PD program (Birman et al., 2000). Two measures of duration are contact time (the total number of hours teachers spent in activities related to the PD program) and time span (the total time the professional development activity covered) (Ingvarson et al., 2005). One of the criticisms of the traditional one-shot inservice programs is that they do not provide enough time for acquisition, practice, feedback, follow-up, and maintenance of new ideas and skills (Henriques, 1998; Kennedy, 1998). Almost all of the recent literature on teacher learning and PD, thus, begs for PD activities that are distributed or sustained over time (Garet et al., 2001). It should be noted that simply increasing the duration of PD does not guarantee teacher change, but without long-term efforts the likelihood is reduced (Hall, 1992; Ingvarson et al., 2005). In other words, the structural features of contact hours and time
span have indirect, but substantial, effects on the outcomes of PD programs (Ingvarson et al., 2005).

More specific evidence for the duration of effective PD comes from research that investigated to what extent PD impacts student achievement because significant change in teachers’ beliefs and attitudes comes after they gain evidence of improvement in the learning outcomes of their students (Guskey, 1985, 1986, 2002). In a review of the evidence for the impact of PD on student achievement in science, mathematics, and reading and English/language arts, Yoon and his colleagues (Yoon, Duncan, Lee, Scarloss, & Shapley, 2007) concluded that regardless of the content area PD had a moderate effect on student achievement across the nine studies. The analysis of the effects by form, contact time, intensity, and duration of PD indicated that the six studies that involved greater than 14 hours of PD showed a positive and significant effect on student achievement while three studies that offered 5-14 hours of PD showed no statistically significant effects on student achievement. Accordingly, elementary science teachers, interest of this study, were most likely to spend very little time in science-related professional development because the 2000 National Survey of Science and Mathematics Education showed that three quarters of elementary science teachers participated in 15 or fewer hours of science related professional development in the last three years (Banilower et al., 2013; Fulp, 2002; Weiss et al., 2001). These findings seemed to suggest that at least 14-hour of PD should be provided to the participants of this study to detect change in teachers’ conceptions of NOS aspects and their beliefs about developmental appropriateness and importance of NOS aspects.
Participation, whether groups of teachers from the same school, department, or grade level participate collectively or teachers from different schools participate individually, is another structural feature of a PD program (Birman et al., 2000). In the literature, there is a growing interest on designing PD for groups of teachers from the same school, department, or grade level rather than targeting inservice programs towards individual teachers (Garet et al., 2001). There are many advantages of using collective participation, as opposed to individual participation, in a PD program. First, teachers who work together are more likely to discuss concepts, skills, and problems that arise during their professional development experience and improve their understandings than teachers who come from different schools (Birman et al., 2000; Garet et al., 2001). As applied to this study, such collaborative participation would provide elementary science teachers the opportunity to improve their understandings of the NOS aspects. Second, teachers who share the same students can discuss students’ needs across classes and grade levels (Birman et al., 2000; Garet et al., 2001). This implies for the present study that elementary teachers from the same school would be more likely discuss their beliefs about developmental appropriateness and importance of NOS aspects than those from different schools. Third, engaging in joint PD may provide teachers of the same school, department, or grade level the opportunity to integrate what they learn to other aspects of their instructional context (Birman et al., 2000; Garet et al., 2001). Such integration might help participants find the NOS activities provided in the PD program meaningful to participate, and thus, enhance their understandings of the aspects of NOS and reconcile their beliefs in terms of whether these aspects are developmentally appropriate and
important to teach for their students. With that being said, targeting elementary teachers from the same school seems to be more advantageous for the purposes of this study.

**Process features of effective professional development.** In their study, Ingvarson and her colleagues (Ingvarson et al., 2005) examined the factors affecting the impact of PD programs on teachers’ knowledge, practice, student learning, and efficacy. These factors included contextual variables (e.g., school support), structural features of PD programs (e.g., duration), process features of PD programs (e.g., active learning), and a mediating variable (the level of professional community generated). They consistently found across the four PD programs that among all factors process features had the largest effect on individual program outcomes. This implies that three process features, which are explained in the following paragraphs, should be incorporated into the design of a PD program to increase its impact on participating teachers’ knowledge, practice, and efficacy and/or their students’ learning.

The first core feature that characterizes the process of learning during a PD program is *content focus*. According to Birman et al., (2000), this process feature represents the degree to which PD focuses on improving and deepening teachers’ content knowledge. They argue that what teachers actually learn in PD activities (that is, the content covered during PD activities) should include knowledge in a specific subject area or knowledge in subject specific teaching method(s) and avoid knowledge about general teaching method(s). In this regard, several studies (Garet et al., 2001; Ingvarson et al., 2005; Kennedy, 1998; Supovitz & Turner, 2000) documented the profound importance of focusing on specific content and how students learn that content in a high-quality PD program. Thus, the PD program in this study focused on improving and deepening
elementary science teachers’ content knowledge about NOS, and to a lesser degree, their knowledge about how students learn NOS.

According to Birman and her colleagues (Birman et al, 2000), active learning which concerns the opportunities teachers are provided to become actively engaged in meaningful analysis of teaching and learning is another core feature of PD activities. They argue that effective PD activities should provide opportunities for active learning, such as observing, being observed teaching, and obtaining coaching or feedback, planning classroom implementation, reviewing student work in the topic areas covered, and presenting, leading, and writing. Research studies (Garet et al., 2001; Ingvarson et al., 2005) also confirm the importance of actively engaging teachers in their own learning. This implies for the present study that the PD activities should provide elementary science teachers the opportunity for active learning of NOS and NOS teaching. These active learning opportunities took a number of forms, including the opportunity to observe and participate in several NOS lessons given by the researcher and university professor, to test some of these NOS lessons in their own classroom, to examine and evaluate examples of students responses about NOS; to discuss how to revise NOS activities for their own students, and to reflect with other participants on how NOS lessons work in their classroom.

A third process feature of PD is coherence, which concerns the extent to which PD activities are coherent part of a wider set of opportunities for teacher learning and development (Birman et al, 2000). This means that effective PD activities should support teachers in developing continued professional communication among teachers (Birman et al., 2000; Henriques, 1998) and incorporate experiences that are consistent with teacher
goals and other activities and aligned with state standards and assessment (Birman et al., 2000). This argument seems to be supported by research studies (Garet et al., 2001; Ingvarson et al., 2005; Supovitz & Turner, 2000). For instance, in their study Garet and his colleagues (2001) assessed the coherence of a teacher’s PD in three ways as Birman and her colleagues (2000) conceptualized. The findings showed that coherence was significantly related to not only increased knowledge and skills but also change in teaching practice. To foster coherence in teacher learning and development, the PD activities in this study included the opportunity to examine and review national and state science standards in terms of NOS, to identify relevant NOS aspects presented in each activity individually and together, to discuss the extent to which NOS activities were appropriate in their classroom and share ideas about how to adapt them for their own students, and to test and reflect on teaching NOS in their classroom.

In summary, an effective PD program whether in a traditional or reform format should have appropriate duration to provide more opportunities for subject-area content focus, active learning, and coherence. In addition to providing sufficient time, it should be school or cite based in order to sustain teacher change via professional community generated in the school. Even though the structure of a PD program plays a crucial role in its impact on teachers’ knowledge and practice and student learning, the nature of activities offered to teachers in the PD program is also very important. The activities of an effective PD program should focus on both the content teachers are expected to teach and how students learn that content, support active learning, and promote coherence with teachers’ other experiences. Reviewing the aforementioned characteristics of an effective PD program helped the researcher in the selection of the two appropriate models to
ground this study. The following section first provides in-depth information about the professional development and teacher change model proposed by Guskey (1985, 1986, 2002) and then the teacher development model by Bell and Gilbert (1996).

The professional development and teacher change models. To describe elementary science teachers’ learning of NOS (i.e., change in teachers’ conceptions of NOS and beliefs about developmental appropriateness and importance of teaching NOS) in the context of a PD program, the present study used Guskey’s (1985, 1986, 2002) model of teacher change and Bell and Gilbert’s (1996) model of teacher development as a theoretical framework.

According to Guskey (1985, 1986, 2002), the common goal of PD programs is to bring about change in three dimensions: (a) change in teachers’ beliefs and attitudes, (b) change in teachers’ classroom practices, and (c) change in the learning outcomes of students. He argued that most of the PD programs initially attempted to change teachers’ beliefs and attitudes because they assumed that such changes would lead to change in teachers’ classroom behaviors and practices, which, in turn, would result in change in student learning (Guskey, 1985, 1986, 2002). Unfortunately, such efforts in the history of PD literature were generally characterized by failures. According to Guskey (1986), the failings of such PD efforts could be explained by the fact that they do not consider “what motivates teachers to engage in staff development and the process by which change in teachers typically takes place” (p. 6). For many teachers, a PD program is attractive if they believe it can help them to become a better teacher through improving their students’ learning outcomes. Thus, Guskey (1985, 1986, 2002) highlighted the need for a new
model that reexamines the order in which the three outcomes of PD programs are most likely to occur.

In his alternative approach, Guskey (1985, 1986, 2002) proposed that the most significant changes in teachers’ beliefs and attitudes most likely come only after classroom implementation was combined with evidence of change in the learning outcomes of their students. This means that PD efforts first should provide opportunities for teachers to take what they have learned in the training to their own classroom and then to receive regular feedback on student learning. Change in teachers’ beliefs and attitudes will follow if they see any cognitive or affective improvements in their students’ learning. See Figure 1 that depicts the process of change in teachers’ beliefs via PD.

![Diagram](image)

*Figure 1. Model depicting theoretical relationship between PD and change in teacher beliefs. Adapted from “Professional Development and Teacher Change,” by T. R. Guskey, 2002, Teachers and Teaching: Theory and Practice, 8, p. 383.*

Different from Guskey (1985, 1986, 2002), Bell and Gilbert (1996) developed their model by analyzing the learning of the teachers involved in their three-year research projects, the Learning in Science Project. Their model represented an overview of the process to change science teachers’ classroom practice and their attitudes and beliefs about teaching science. The model, which takes a social constructivist perspective of teacher development, has three main features. The first one is the description of three types of development that teachers undergo: professional (cognitive and action
development), personal, and social. The second central feature of the model is the premise that learning takes place within the context of a teacher-development program that involves support, feedback, and reflection. The third feature is that there is no prescribed time or sequence for teachers to undergo the aspects of development. Teachers progress through situations, or phases, of (a) confirmation and desiring change, (b) reconstruction, and (c) empowerment that are interrelated and interdependent (not a stage-like teacher development).

According to Bell and Gilbert (1996), social aspect of teacher learning involves developing new ways of working with and relating to other teachers and students to renegotiate and reconstruct the rules and norms of what it means to be a teacher. They suggest that PD activities including opportunities for the support from colleagues and school management can contribute to the social development of teachers because such opportunities would enable the kinds of social interaction and communication necessary for renegotiating and reconstructing of what it means to be a teacher. To support social development, the researchers sought opportunities for the study participants to discuss their ideas with other teachers, and to collectively renegotiate and reconstruct what it means to teach NOS and be a teacher of NOS.

Personal development of teachers involves constructing, evaluating, and accepting or rejecting the new socially constructed knowledge of what it means to be a teacher of science and managing the feelings and concerns associated with changing their activities and beliefs about science education (Bell & Gilbert, 1996). Their concerns include fear of losing control in the classroom, the amount and type of teacher involvement, covering the curriculum, knowing the subject, meeting assessment requirements, the criteria used to
judge their performance, and relationships with students. Hence, PD programs should address these personal development feelings and concerns that have both a cognitive and an affective strand to the task (Bell & Gilbert, 1996). In this study, personal development was addressed in two ways. First, the participants of this study were selected in a way that they felt a desire or a need for acquiring new ideas about science or for changing their science teaching in terms of NOS. Second, the PD activities included opportunities to show the place of NOS in the science education standards, develop a sense of trust to NOS teaching activities, and make them feel empowered by contributing the group discussions about NOS and NOS teaching.

Professional aspect of teacher learning occurs as teachers engage in cognitive development and the development of classroom practice (Bell & Gilbert, 1996). Crucial to this process is an acceptance of the newly accepted ideas and beliefs about science education. The acceptance or rejection of cognitive development is based on reliable, empirical evidence grounded in the use of new activities in the classroom and feedback received about others’ use of the activities. Thus, PD programs should include opportunities that allow teachers to test out new teaching activities, examine personally and socially constructed beliefs and conceptions underlying their actions, and plan new actions. To support professional development of the study participants, the researchers created settings that allowed them to use the newly acquired NOS conceptions and teaching skills and then reflect on these learning and teaching experiences via discussions and formal or informal meetings.
Chapter 3 Methodology

Introduction

The purposes of this study were to: 1) examine the participating elementary teachers’ conceptions of NOS and their beliefs about the developmental appropriateness and importance of teaching NOS over the course of an academic-year long, professional development program and 2) identify the components of the professional development program that the elementary teachers perceive effective in changing their conceptions of NOS and beliefs about the developmental appropriateness and importance of teaching NOS. Therefore, this study was exploratory and interpretive in nature (LeCompte & Priessle, 1993). Data collection was continuous and spanned the duration of the study. Numerous data sources were used to answer the following guiding research questions:

1. How did the elementary science teachers’ conceptions of the target NOS aspects change over the course of participation in an academic-year long, professional development program on NOS?

2. How did the elementary science teachers’ beliefs about the developmental appropriateness and importance of teaching the target NOS aspects change over the course of participation in an academic-year long, professional development program on NOS?

3. Which components of the professional development program did the participating elementary teachers perceive as effective in changing their conceptions and beliefs about the developmental appropriateness and importance of the target NOS aspects?
A qualitative research approach is selected to understand the elementary teachers’ conceptions of NOS and their beliefs about the developmental appropriateness and importance of the NOS ideas over the course of a yearlong professional development program. A qualitative study is more appropriate than a quantitative study to investigate the aforementioned research questions because the intent of qualitative research is to explore a complex phenomenon and present the varied meanings that participants hold (Creswell, 2009).

**Design of the Study**

In the field of education, the five most commonly used types of qualitative research are the basic or generic qualitative study, ethnography, phenomenology, grounded theory, and case study (Merriam, 1998). Among these five qualitative research designs, a case study was used in this study to conduct an investigation of elementary teachers’ conceptions of NOS and their beliefs about the developmental appropriateness and importance of the NOS ideas during a professional development program.

According to Merriam (1998), case studies are “particularistic,” meaning that the case study focuses on a “particular situation” or “phenomenon.” This study was particularistic because it focused on NOS learning of teachers who participated in a yearlong professional development program on NOS and worked at a high achieving school in a southwestern state of the United States, a phenomenon in a particular situation.

According to Yin (1994, 2003), “a case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context,
especially when the boundaries between phenomenon and context are not clearly confident” (p. 13). This study aimed to investigate the aforementioned phenomenon in depth and within the context of the elementary school setting. In other words, the case-study design was used because of its ability to give “intensive descriptions and analyses of a single unit or bounded system such as an individual, program or groups” (Merriam, 1998, p. 19) and to cover “contextual conditions” (Yin, 1994, 2003, p.13).

For case studies, there are four types of designs, which are named based on the number of cases and units of analysis (Yin, 1994, 2003). The primary distinction in designing case studies is whether a single-case study or multiple cases are used to address the research questions (Yin, 1994, 2003). The present study included multiple cases in order to understand the relationships among elementary teachers’ conceptions of NOS with respect to the target aspects of NOS, their beliefs about the developmental appropriateness and importance of the target NOS aspects, and various components of the professional development program. Each case in this study was an elementary teacher (i.e., a third or fifth grade teacher) who voluntarily participated in all components of the professional development program.

This research investigated four elementary science teachers during their participation in the professional development program with the goal of determining the factors that made teachers enhance their conceptions of NOS regarding the target aspects and find teaching the target NOS aspects more developmentally appropriate and important for their students. The use of more than one case is advisable because of two reasons: (a) analytic conclusions arising from multiple cases are likely to be more
powerful than a single-case and (b) the external validity of the findings is strengthened if they are obtained from multiple cases compared to a single case (Yin, 2003).

In addition, the embedded case-study design was used in this study. According to Yin (1994, 2003), this design is desirable when research involves more than one unit of analysis. Within each case, the researcher focused on the conceptions of NOS and beliefs about the developmental appropriateness and importance of teaching NOS and analyze these units with data from a variety of sources (questionnaires; interviews; observations, including videotaped meetings; the researcher’s reflective field notes; and the professional development artifacts).

**Setting**

The participants of this study worked at a school located in the southwest region of the United States. The school is a K-12 state sponsored tuition free public charter school with emphasis in the areas of Math, Science, and Technology. The selection of the school was based on its convenience. First, the researcher had some personal contacts with the administrators and teachers of this school because she has been voluntarily serving as a judge in the science fair projects for the last three years. Second, this school was designated as a high achieving school by the State Department of Education two years in a row and successfully met Adequate Yearly Progress (AYP) for the past 2011-2012 academic year. Having some communication with the school administration and teachers and being a high achieving school that gives importance to science teaching created a very convenient setting to provide a professional development program on NOS and to maximize the number of participating teachers, given that no compensation (a
stipend or a certification) was provided at the conclusion of the study unlike previous studies (e.g., Akerson et al., 2009a; Akerson et al., 2007; Posnanski, 2010).

The school has three different campuses for the grade spans of K-2, 3-5, and 6-12. The elementary campus of the school that serves grades 3-5 was purposefully selected for this study because there is a limited number of research studies (e.g., Akerson et al., 2009a; Akerson & Hanuscin, 2007) that provided a professional development program for this particular grade band. The elementary science teachers who were working at this campus were the focus of this study. The elementary campus of the school had a total of eight science teachers. Of the elementary science teachers, the ones who consented to participate in the research as well as the professional development program and who remained with the program until its conclusion were purposefully selected for case studies.

Participants

Of eight science teachers at the elementary school, four of them consented and volunteered to participate in the present study reviewed and approved by the Internal Review Board (IRB) at University of Nevada Las Vegas (UNLV) (See Appendix B for the UNLV IRB Approval form). The following paragraphs provide more information about these four elementary science teachers who showed their commitment to complete all of the phases of the professional development program (i.e., the NOS training and NOS teaching).

Of the three third grade science teachers at the school, Francine was the only teacher who remained with the professional development program until its conclusion. She was 36 years old, nonnative elementary teacher. Throughout her undergraduate
years, Francine took only three science content courses. She was certified in Elementary K-8 Education, but she also had a master’s degree in Gifted Education. Francine had been teaching science at the third grade level for five years. She expressed that on average she spent between four and five hours each week teaching science.

The second case in the present study was Anna, who was one of the three fifth grade teachers at the school and completed all parts of the professional development program. She was 42 years old teacher certified in Elementary K-8 Education and Administration. Throughout her undergraduate years, Anna took five science content courses. She had eight years of science teaching experience and spent between four to five hours each week teaching science in her classrooms.

Among all participants, Nancy was the only teacher who did not have any science teaching experience and who was a new teacher at the school. Before this school, she taught all subjects except science at the third grade level for one year and she taught language arts and social studies at the sixth grade level for two years. In other words, Nancy also did not have any teaching experience at the fifth grade level prior to the professional development program. She was 45 years old teacher certified in Elementary K-8 Education and Administration. Throughout her undergraduate years, Nancy took only three science content courses. As a new fifth grade science teacher, she was not sure how much time she would spend teaching science in her classrooms, yet she planned to teach at least two hours of science each week.

Andy was another fifth grade science teacher at the school who completed all parts of the professional development program. He was a 32-year-old teacher certified in Elementary K-8 Education. Compared to a regular elementary teacher, Andy took
significantly more science content courses in college (i.e., seven science courses). He had been teaching fifth grade science for six years at the school. In addition to the fifth grade science teaching experience, Andy also had one year of third grade science teaching experience and one year of sixth grade reading, writing, and social studies teaching experience. He expressed that on average he spent between four and five hours on teaching science each week.

Data Sources

Qualitative data sources were used to develop a rich picture of the participants’ conceptions of NOS and their beliefs about the developmental appropriateness and importance of the NOS ideas, as well as the changes in their conceptions and beliefs over the course of the professional development program. The study data were collected from multiple sources: Primary data sources included questionnaires and interviews, while secondary data sources included videotaping of meetings with teachers, the researcher’s reflective field notes, and artifacts produced in the professional development program and in the participants’ classroom teaching.

Questionnaires. This study administered two different questionnaires, one for the conceptions of NOS and the other one for the beliefs about importance and developmental appropriateness of the NOS ideas. The following paragraphs describe these two questionnaires in detail.

The Views of Nature of Science questionnaire. The Views of Nature of Science Questionnaire-Form VNOS-D2 (Views of Nature of Science Elementary School Version 2) developed by Lederman and Khishfe (2002) was utilized in the present study. This 10-item open-ended instrument was selected to elucidate, describe, and characterize the
participants’ conceptions of NOS and assess changes in their NOS conceptions as a result of their participation in the professional development program. The VNOS-D2 is a modified version of the VNOS-C (Lederman et al., 2002) to be used with elementary audiences. This instrument has been extensively used in previous research studies with inservice and preservice elementary teachers (e.g., Akerson et al., 2009a; Akerson et al., 2007; Akerson et al., 2009b; Cullen et al., 2010; Hanson, 2006) as well as elementary students (e.g., Akerson et al, 2014; Akerson et al., 2011).

An open-ended questionnaire was intentionally used in the present study to avoid previously identified problems inherent in the use of standardized paper and pencil instruments to assess the learners’ conceptions of NOS. First, Lederman and O’Malley (1990) argued that these instruments are based on a problematic assumption that respondents perceive and interpret an instrument’s items in the same manner that the instrument developers and/or researcher(s) would, and choose certain responses for the reasons that corresponds to those of the instrument developers and/or researcher(s). Second, Lederman et al. (1998) noted that these traditional paper and pencil instruments usually reflect their developers’ NOS views and biases due to their *forced-choice* response format (e.g., agree/ disagree, a Likert-type scale, or multiple choice response). In contrast, open-ended items allow participants not only elucidate their own views about NOS but also the reasons behind their views (Lederman & O’Malley, 1990).

The nine-item open-ended questionnaire was utilized in the present study (refer to Appendix C for the questionnaire). One item that was purported to assess an individual’s conception of NOS aspect concerning the relationship and difference between scientific laws and theories was omitted from the VNOS-D2 questionnaire because K-5 elementary
teachers, sample of interest in this study, are not expected to teach this NOS aspect to their students according to major science education reform documents in the United States (e.g., AAAS, 1993, 2009; NGSS Lead States, 2013; NRC, 1996). See Appendix C for the nine-item version of the VNOS-D2 questionnaire utilized in the present study.

**Ideas about Science for Early Elementary (K-4) Students.** In the present study, a modified version of Sweeney’s (2010) Ideas about Science for Early Elementary (K-4) Students questionnaire was used to measure the participating elementary teachers’ beliefs about the developmental appropriateness and importance of the nine NOS aspects for third through fifth grade students. The modified version of the beliefs questionnaire is included in Appendix D.

Sweeney’s (2010) Ideas about Science for Early Elementary (K-4) Students questionnaire was based on Alshamrani’s (2008) Key Aspects of the Nature of Science (KA-NOS). Sweeney (2010) adapted the KA-NOS in terms of wording and format in order to be used it as a written survey instrument for the sample of elementary teachers in her study because Alshamrani (2008) originally developed the KA-NOS as a coding protocol for evaluating NOS elements in textbooks for K-12 science education. In her study, Sweeney (2010) used four content experts to ensure the content validity of the questionnaire and Cronbach’s coefficient alpha (α) to determine internal consistency. The obtained Cronbach’s coefficient alpha value in her pilot study (α = .91) indicated that the items in the questionnaire were highly correlated, and thus, measured NOS.

In Sweeney’s (2010) original questionnaire, each *idea about science* (or each NOS aspect) is defined to elicit teachers’ perceptions about NOS rather than to assess their knowledge about it. Following the description of each idea about science, the
respondents are asked to evaluate the developmental appropriateness and importance of that particular idea about science (or that particular NOS aspect) and then they were asked to indicate their plans for introducing each NOS aspect in the curriculum for a particular school year.

Four changes were made to this questionnaire in line with the purposes of this research study. The first change was related to the response format of the developmental appropriateness question for the ideas about science. In the original questionnaire, the respondents indicated their opinion about the developmental appropriateness of each idea related to science by responding yes or no to the prompt: “Do you feel this idea is developmentally appropriate for the grade level(s) you currently teach?” In the modified questionnaire utilized in the present study, the respondents were asked to respond the same prompt, but they indicated their opinion about the developmental appropriateness of each NOS aspect on a 5-point Likert Scale (ranging from not at all appropriate [1] to very appropriate [5]) and along with their reasoning for the given rating. This enabled the researcher to delve into to what degree and why the teachers considered each NOS aspect appropriate for the grade level they taught at the time of the study. The use of 5-point Likert Scale, as opposed to yes or no, as a response format also eliminated some problems related to the reliability analysis that Sweeney (2010) faced in her study. First, she could not include the item related to the empirical NOS in the reliability analysis because all of the participants indicated that this idea was developmentally appropriate at their grade level(s). Second, some teachers in her pilot study questioned what to do if they partially agree on the developmental appropriateness of a particular idea.
The second change in the questionnaire was related to the wording of the question about the importance of a particular idea about science. In the original questionnaire, Sweeney (2010) decided to use the word *introduce* rather than *teach* after her pilot study because the word *teach* meant for some teachers that students should master the whole idea, whereas the word *introduce* would convey such an idea that it is okay for students to get part of the idea. In the modified questionnaire, the researcher decided to change the word *introduce* back to the word *teach* because the participants of this study were asked to teach, as opposed to introduce, NOS in their own classrooms as a part of the professional development program. Like the developmental appropriateness question, the respondents were also asked to write the reason for their rating to the prompt: “*How important do you feel it is to teach this idea in the grade level you currently teach?*” The inclusion of the reasoning behind their rating enabled the researcher to eliminate the problem associated with the use of word *teach* rather than the word *introduce* and also to gain more information about the participating teachers’ rationale(s) for teaching NOS.

Consistent with the second change made to the questionnaire, the respondents were asked to indicate their plans for teaching, rather than including, each NOS aspect in the curriculum for a particular school year or a particular part of the semester in the modified version of the questionnaire. Necessary adjustments were made for the three occasions of the questionnaire administration and shown in parentheses in Appendix D. In the first administration of the questionnaire, the respondents were asked to indicate their plans for teaching each NOS aspect for the school year when the professional development took place (e.g., I plan to teach this idea this school year). In the second administration of the questionnaire, the time expression of “this school year” was
changed into “by the end of this semester” because the participants were approached to the end of school year by the time they began to teach NOS in their own classrooms (e.g., I plan to teach this idea by the end of this semester). Moreover, the researcher also added one more response option, “I do not plan to teach this idea at all”, to the part on the questionnaire where the participants described their plans for teaching each NOS aspect. The reason for the addition was to elicit the participants’ possible thoughts about whether their exclusion of a particular NOS aspect is not unique to the school year during which the present study was conducted. For a different school year, some participants might present different plans for teaching NOS aspects. In the third administration of the question, the time expression of “by the end of this semester” was changed into “next school year” because the participant completed teaching NOS in their own classroom for the particular school year. Moreover, the questionnaire was administered orally because of the short time period between the second and third administration.

The last change made to the questionnaire was about the number of items. As presented earlier in this document, all four sources of NOS recommendations for science education (i.e., the three major science education policy documents and NOS research literature at the elementary grade levels) agree that teaching the NOS idea, “there is a distinction between scientific laws and theories”, is not appropriate for K-5 elementary students. Therefore, this NOS idea was excluded from the questionnaire that was used with K-5 elementary teachers. In addition to the idea about the relationship between theory and law, the two ideas about the importance of experimentation in science and the relationship between science and technology were removed from the questionnaire.
because none of these ideas were the focus of current academic research or questionnaire on NOS.

Finally, in line with the purposes of this study the modified version of the questionnaire did not include the item about which ideas about science the respondents remember are included in their state’s K-4 science standards. Instead, the researcher added two more items that asked the respondents to rank the nine NOS ideas from 1 indicating the most appropriate or important NOS idea to 9 indicating the least appropriate or important NOS idea, respectively. Given the perspective that science instruction is “nearly extinct” and teachers are “not teaching enough” science in elementary grades (Asimov, 2007; Martindale, 2011), the respondents’ beliefs about the relative developmental appropriateness or importance of a particular NOS idea would play a greater role than their beliefs about individual developmental appropriateness or importance of a particular NOS idea in teaching this NOS idea in the classroom. Therefore, the addition of these two items enabled the researcher to better elicit the respondents’ beliefs about developmental appropriateness and importance of teaching the NOS ideas in elementary classrooms.

**Interviews.** The researcher conducted two interviews: one for the conceptions of NOS and the other one for the beliefs about developmental appropriateness and importance of the NOS ideas. The following paragraphs describe in details how these two interviews were conducted in the present study.

**The views of NOS interview.** In line with the recommendations of Lederman and O’Malley (1990), the researcher conducted semi-structured interviews at the beginning of the professional development program, at the end of the NOS training, and after the
completion of the participants’ NOS teaching in their classrooms (See Appendix E for the interview protocol used in the present study). The interviews served three purposes. First, the individual interviews were used to establish the validity of the VNOS-D2 questionnaires administered at the beginning and end of the NOS training. Given that the present study delved into the meanings that participants ascribed to the target NOS aspects over the course of professional development program, it was imperative to avoid misinterpreting the participants’ responses to the questionnaire. Therefore, the use of interviews along with the questionnaire enabled the researcher to ensure that her interpretations corresponded to those of participants.

Second, the interviews enabled the researcher to generate in-depth descriptive profiles of the participants’ NOS conceptions. During the interviews, the participants were provided with their written responses on the corresponding questionnaire and asked to read, explain, elaborate and/or justify their responses. Note that the researcher had to conduct the post-NOS teaching interview on the participants’ NOS conceptions without administering the VNOS-D2 questionnaire because there was a short time period between the last two interviews. During each of the three interviews, follow-up questions were used to clarify participants’ responses and to further probe their lines of thinking. Such descriptive profiles of the participants greatly contributed to the meaningfulness and importance of the gains in the participants’ conceptions of NOS (Abd-El-Khalick & Lederman, 2000). In other words, interviews also provided important information regarding the perceived changes in participants’ conceptions of NOS and the attributions for these changes.
Third, the interviews also served as one form of “member check” (Lincoln & Guba, 1985). During the hour-long interviews, participants were asked to (a) elaborate on their responses, (b) discuss whether they felt any of their NOS conceptions were influenced as a response to their participation in the NOS training and their NOS teaching, and (c) share their perceptions about which element(s) of the professional development program were more responsible for the change, if at all, they expressed in their conceptions of NOS. This allowed the researcher to compare her initial interpretations and/or comparisons of VNOS-D2 data with participants’ verbal responses. Each of the interviews lasted approximately an hour. They were audio-taped and transcribed in verbatim for the data analysis.

**Ideas about Science for Early Elementary (K-4) Students interviews.** The researcher conducted semi-structured interviews at the beginning of the professional development program, at the end of the NOS training, and after the completion of the participants’ NOS teaching in their classrooms by using the Ideas about Science for Early Elementary (K-4) Student Questionnaire (Sweeney, 2010) [called beliefs questionnaire hereafter]. The interview protocol, which was developed by the researcher, was used to assess the participants’ beliefs about developmental appropriateness and importance of the target NOS ideas (See Appendix F for the interview protocol). During the pre- and post-NOS training beliefs interviews, the researcher provided participants their responses on the Ideas about Science for Early Elementary (K-4) Student Questionnaire (Sweeney, 2010) and asked them to read, explain, and justify their responses. However, the researcher had to conduct the post-NOS teaching beliefs interview without administering the beliefs questionnaire because there was a short time period between the last two
interviews. The use of the interviews along with the self-report questionnaires provided more in-depth and richer picture of participants’ beliefs about the developmental appropriateness and importance of the target NOS ideas for their own students. During each of the three interviews, the researcher asked follow-up questions to clarify to what extent the participants considered teaching a particular NOS idea as developmentally appropriate and important at their grade level, and to further probe the reasons for their beliefs about developmental appropriateness and importance of the target NOS ideas.

The hour-long interviews after the NOS training and the NOS teaching were somewhat different from the pre-NOS training interview because the participants were also asked to discuss whether they felt any of their beliefs about the developmental appropriateness and importance of the target NOS ideas changed and which professional development experience or activities were more responsible for the change, if at all, they expressed in their beliefs.

In summary, the use of interviews allowed the researcher to compare her initial interpretations of the data with participants’ verbal responses regarding their beliefs about the developmental appropriateness and importance of particular NOS ideas for their own students. In other words, these interviews also served as one form of “member check”, described by Lincoln and Guba (1985).

Each of these three interviews lasted approximately an hour. They were audio-taped and then transcribed in verbatim for the data analysis.

**Videotaping of Meetings.** The meetings with teachers were videotaped to document the professional development program. These videotapes, along with the researcher’s reflective field notes and handouts from meetings were used (a) to ensure
that explicit-reflective NOS took place by the researcher and the science education professor, (b) to keep track of which NOS aspects were addressed at each meeting, and (c) to plan for future professional development activities. They were also used as supplemental data sources to be referred to evaluate the effectiveness of the various components implemented in the professional development program, when it is required. In other words, the videotapes were used to support interview data about what types of learning experience contributed to the change in the conceptions of, or beliefs about NOS aspects being studied and what characteristics of the professional development program caused it to be more or less effective.

**Professional Development Program**

As presented in the literature review, research on professional development and NOS provided guidance for the components and design of the professional development program that was employed in this study to promote changes in the participating elementary science teachers’ conceptions of NOS and their beliefs about the developmental appropriateness and importance of NOS.

Following Bell and Gilbert’s (1996) social constructivist teacher development model, the professional development program addressed and supported three components: (a) *social development* in which the researchers provided opportunities for teachers to discuss ideas with other teachers, and to collectively renegotiate and reconstruct what it means to teach science and be a teacher of science, (b) *personal development* in which the participants of this study were selected in a way that they felt a desire or a need for acquiring new ideas about science or for changing their science teaching in terms of NOS, and (c) *professional development* in which the researchers
supported teachers to implement new ideas and strategies in their own classrooms and then reflect on these learning and teaching experiences via discussions and formal or informal meetings for subsequent development of beliefs and conceptions.

Additional characteristic of successful teacher development model is that teachers need an extended period of time, rather than “one-shot” workshops, for change to occur (Akerson & Hanuscin, 2007; Loucks-Horsley, Hewson, & Love, 2003). Therefore, the duration of the professional development program in this study was intentionally extended over one academic year. This study included two phases: the NOS training and the NOS teaching. The first phase (the NOS training) took about 6 months and it was geared towards developing participants’ conceptions and beliefs about NOS and NOS teaching. There was a total of 13 face to face meetings during the NOS training. After the first phase was completed, the participants met once to plan their NOS teaching which would take place in the second phase of the professional development program. In that week, the participants selected which NOS activities, and in which order, they would teach them in their classrooms and revise, if necessary, the NOS poster for their own students. The second phase (the NOS teaching) took about one month and it was designed to provide opportunities for participants to practice teaching NOS in their own classrooms. Participants taught at least four NOS lessons during the NOS teaching. During the second phase participants met once to collectively reflect on their NOS teaching and their students’ experience in learning NOS.

In designing the professional development program, the researcher also drew upon prior research on preservice and inservice teachers’ conceptions of NOS. The findings of these studies (e.g., Akerson & Abd-El-Khalick, 2003; Abd-El-Khalick &
Akerson, 2004; Akerson et al., 2000) have pointed out the effectiveness of an explicit-reflective approach over implicit approaches for helping teachers both learn and teach NOS. Therefore, the training provided in the first phase of the professional development program was developed around the explicit-reflective instructional approach. The following paragraphs describe in detail how this approach was implemented in the NOS training.

The researcher and the professor started the NOS training with the Bottle activity by using explicit-reflective instruction in which the elementary teachers’ participation in the activity was followed by the instructors’ intentional attempts to connect NOS aspects to the salient parts of the activity. They used the NOS poster (See Appendix H) and written definitions of NOS aspects (See Appendix A) as visual aids when we connected NOS aspects to the NOS activity. This first NOS activity allowed us to realize the need for structured reflection during the explicit-reflective instruction. Therefore, the researcher prepared written scaffolds that facilitated individual and group reflection. These written scaffolds were consistently used during the rest of the NOS training. The first part of the reflection focused on making target NOS aspects more accessible for them to understand and the second part of the reflection focused on pedagogical aspects of teaching the NOS activity in their own classroom. Please see Appendix I for structured reflection worksheet specifically designed for one of the activities in the NOS training.

During the NOS training, the researcher and professor explicitly introduced and reinforced the meanings of the nine aspects of NOS: empirical, inferential, tentative, creative, subjective, sociocultural, collaborative, and bounded NOS, and the absence of a single scientific method. In this regard, they used hands-on NOS activities, readings, and
visual aids included in previous research with elementary teachers or students. Moreover, they used discussion and questioning to intentionally draw teachers’ attentions to relevant NOS aspects during the NOS training.

Appendix G provides a list of instructional materials used in the NOS training based on the review of the aforementioned NOS research and teacher development models. Moreover, it also gives brief information about how and what purposes these instructional materials were used in the NOS training and which NOS aspects, if applicable, were addressed via these instructional materials.

**Data Collection**

To explore the changes in the conceptions of NOS that may be attributed to participation in the PD program, each participant’s conceptions of NOS were assessed at the start of the PD, after the NOS training, and after the NOS teaching. As recommended by the developers of the instrument and other VNOS instruments (e.g., Lederman et al., 2002; Lederman & O’Malley, 1990), each participant was interviewed using the VNOS-D2 (Lederman & Khishfe, 2002). These transcribed audiotaped interviews allowed the participants to elaborate on and clarify their conceptions of NOS as well as their perceptions of which component(s) of the PD were much more responsible for the change, if any. In addition, they allowed the researchers to validate their interpretation of the participants’ written responses on the pre- and post-NOS training questionnaires.

In a similar vein, to explore the changes in beliefs about the developmental appropriateness and importance of the NOS aspects, each participant was interviewed at the start of the PD, after the NOS training, and after the NOS teaching by using the modified version of Sweeney’s (2010) Ideas about Science for Early Elementary (K-4)
Students questionnaire. These transcribed audiotaped interviews allowed the participants to elaborate on and clarify their beliefs as well as their perceptions of which component(s) of the PD were more responsible for the change, if any. In addition, they allowed the researchers to validate their interpretation of the participants’ written responses on the pre- and post-NOS training questionnaires. Figure 2 shows a timeline of data collection and interventions during the course of study.

**Figure 2.** Overview of the study.
Data Analysis

The data of this study were analyzed using pattern matching, explanation building, and cross-case synthesis (Yin, 1994, 2003). Pattern matching is a comparative analysis that looks for coinciding patterns from each case to identify evidence that will support the predicted outcome (or alternative outcomes). Explanation building, which is a specific type of pattern matching, is used to develop a general explanation about the case as a result of a series of iterations. If an explanation cannot be built as a result of this iterative process, cross-case analysis may start. In the technique of cross-case synthesis, each individual case study is treated as a separate study and the analysis looks for whether different groups of cases share some similarity to be considered as the same type of general case (Yin, 1994, 2003). The following three sections explain how the researcher implemented the three analysis techniques described by Yin (1994, 2003) to answer each of the research questions.

The first and second research questions guiding the present study explored the changes in the participating elementary teachers’ conceptions of NOS (and their beliefs about the developmental appropriateness and importance of NOS ideas) as a result of their participation in the professional development program. To answer these questions, data collected via questionnaires and interviews were analyzed within case and then across cases. First, the researcher thoroughly read each participant’s questionnaire to generate a summary of the participant’s conceptions, and beliefs about the developmental appropriateness and importance, of the target NOS aspects. The summaries were then searched for initial patterns or categories. The generated patterns or categories were checked against confirmatory or otherwise contradictory evidence in the questionnaire.
data and modified accordingly. The process of pattern or category generation, confirmation, and modification were conducted many times as needed. The same process was repeated with the corresponding interview transcripts. The patterns that were generated from the independent analysis of the questionnaires and interviews was then compared and contrasted to generate the profiles of the participants’ conceptions (and beliefs about the developmental appropriateness and importance) of the target NOS aspects.

Next, all questionnaires and interviews were analyzed to generate pre-NOS training, post-NOS training, and post-NOS teaching profiles of participants’ conceptions of NOS (and beliefs about the developmental appropriateness and importance of NOS ideas). In this analysis, each participant was treated as a separate case.

Third, pre-NOS training, post-NOS training, and post-NOS teaching profiles of participants’ conceptions of NOS (and beliefs about the developmental appropriateness and importance of the NOS ideas) were compared to identify the changes in conceptions (and beliefs about the developmental appropriateness and importance of the NOS ideas).

Finally, the researcher holistically looked for general patterns in the changes of NOS conceptions (and beliefs about the developmental appropriateness and importance of the NOS ideas) across the cases as a result of NOS training and teaching.

The third research question of this study investigated the participants’ perceptions of what components of the PD program contributed to their conceptions of NOS and their beliefs about the developmental appropriateness and importance of the NOS ideas. To answer this question, the researcher thoroughly read each teacher’s transcripts of post-NOS training interview and post-NOS teaching interview, and searched for initial
patterns. This initial analysis was conducted separately for the conceptions of NOS and beliefs about the developmental appropriateness and importance of the NOS ideas. The generated patterns were checked against confirmatory or otherwise contradictory evidence in the videotapes of meetings and the PD artifacts and modified accordingly. Then these generated patterns were compared and contrasted across cases to identify which component(s) of the PD were commonly found valuable in changing the conceptions of NOS and beliefs about the developmental appropriateness and importance of the NOS ideas.

The Quality of Research

According to Yin (1994, 2003), there are four tests to judge the quality of any empirical social research, including case study research: (a) construct validity, (b) internal validity, (c) external validity, and (d) reliability. In the present case study research, different tactics were applied to deal with these four tests. The following section provides detailed information how the quality of this case study research was ensured.

Construct validity. The present case study research used multiple sources of evidence (Yin, 1994, 2003) and data triangulation (Denzin, 1984; Patton, 1987) to increase construct validity. The following paragraphs define these tactics and then explain how they were applied in the study.

The case study research requires the collection of different types of evidence or data from multiple sources to ensure construct validity (Yin, 1994, 2003). According to Yin (1994, 2003), the six commonly used sources of evidence in case study research are documentation, archival records, interviews, direct observations, participant-observation, and physical artifacts. The present case study research used three of them: interviews,
participant-observation, and physical artifacts. Additionally, surveys (See Appendices B and C for the open-ended questionnaires) were used as source of evidence. In this study, audiotaped semi-structured interviews were used to corroborate with the written responses on the questionnaires and information from other sources such as videotapes of the meetings, the researcher’s field notes, and the PD artifacts. Over the course of this study, the researcher was not merely a passive observer. Instead, she also served as one of instructors in the NOS training, recorded each meeting with teachers, and kept reflective field notes during or after meetings and interviews. In other words, she served the dual roles of designing and providing the PD program as well as conducting research on teacher learning in the program. Finally, the researcher collected all handouts that were completed by the teachers during the NOS training and by the students in the teachers’ classroom practice.

With the use of the multiple sources of evidence, this study aimed to achieve converging lines of inquiry (Yin, 1994, 2003), as it refers to data triangulation by Denzin (1984) and Patton (1987). With data triangulation, this study dealt with the potential problems of construct validity because the multiple sources of evidence allowed the researcher to measure the same phenomenon in different contexts and looked for whether they remained the same or not.

**Internal validity.** Internal validity, which mainly deals with spurious effects, is a concern only in explanatory case study research (Yin, 1994, 2003). Given that the present case study was explanatory in nature, it employed the analytic tactics of pattern matching and explanation building (Yin, 1994, 2003) described earlier in this document, used member checking (Lincoln & Guba, 1985), used peer review or debriefing (Lilcoln &
Guba, 1985, 1999), and clarified the researcher’s bias (Creswell, 2007; Merriam, 1998) to handle with threats to internal validity.

According to Lincoln and Guba (1985), member checking is “the most crucial technique for ensuring credibility” (p. 314). They define member checking as a process in which collected data are ‘played back’ to the participant to check for perceived accuracy and adequacy. In this study, the researcher used this technique during interviews by asking participants whether her initial interpretation or summary correctly and sufficiently reflected the participant’s conceptions of NOS or beliefs about the developmental appropriateness and importance of particular NOS ideas. Even though Lincoln and Guba (1985) advocate the use of member checking, they also inform researchers not to use this technique when they have doubts about the integrity of the participants. Thus, during interviews the researcher frequently reminded the participants that freely state if they did not agree with the initial interpretation or summary presented by the researcher.

A peer review or debriefing, which refers to an external check of the inquiry process, is another way to ensure internal validity (Lilcoln & Guba, 1985, 1999). This reviewer is the researcher’s peer who is expert in the area of the inquiry and the methodological issues. The rationales behind the inclusion of a peer in the inquiry process are that s/he can keep the researcher honest; ask challenging questions regarding methods, meaning, and interpretations; and help the researcher to clear the mind from emotions or feelings that may affect the quality of the inquiry (Lincoln & Guba, 1999). In this study, it was asked to a peer who is a well-known researcher in the field of personal
epistemology to comment on the methodology of the study. Moreover, the advisor peer-reviewed the findings of this study after the researcher analyzed the data.

Finally, a researcher can achieve the internal validity of the study by clarifying and giving information regarding his or her assumptions, worldview, position, and theoretical orientation, and past experiences that might affect the study (Creswell, 2007; Merriam, 1998). The findings of the present study might be biased due to the researcher’s theoretical orientation that explicit-reflective NOS instruction is effective in improving NOS conceptions of learners. This might have affected the interpretation of the data in a way that teachers should change their NOS conceptions in a positive way. To reduce such influences on data interpretation, during the interviews the researcher asked explicitly whether teachers perceived any change in their NOS conceptions and whether this change could be attributed to their participation in the PD program. Moreover, the researcher assumed that teachers would find NOS more important and developmentally appropriate after the completion of the PD program because of the change in their own NOS conceptions. Such an assumption might have affected the researcher’s interpretation of the influences of the PD program on teachers’ beliefs about the developmental appropriateness and importance of the target NOS ideas. The researcher handled this assumption by including an interview question that explicitly asked teachers whether and how they thought their beliefs about the developmental appropriateness and importance of the particular NOS ideas were influenced after the NOS training and NOS teaching.

**External validity.** External validity deals with to what extent a study’s findings are generalizable beyond the participants or setting under study (Yin, 1994, 2003). The issue of generalization is one of the frequent criticisms of case study research. People
typically state that the findings coming from single cases are not widely applicable in real life. According to Yin (1994, 2003), these people confuse multiple cases with the sample of cases or the small sample size of cases. Such understanding of generalization follows “sampling” logic, which is appropriate as doing studies that look for statistical generalization. Unlike such survey or experimental studies, case studies rely on theoretical generalization, in which “previously developed theory is used as a template with which to compare the empirical results of the case study” (Yin, 2003, p. 33). That being said, Yin (1994, 2003) refuted the criticism of the generalizability in doing case studies by presenting a well-documented difference between statistical generalization and analytic generalization.

In case studies, the external generalizability of the findings can be strengthened with the use of multiple-case designs because such designs follow the logic of replication rather than the sampling logic (Yin, 1994, 2003). For example, if you have more than one case, it is more likely that these cases will differ to some extent. Thus, reaching common conclusions from these multiple cases implies that you have the possibility of direct replication (Yin, 1994, 2003). In this study, external validity was established with the use of the multiple-case design.

Moreover, Lilcoln and Guba (1985, 1999) argue that the researcher can establish transferability with thick description. This means that describing a phenomenon in sufficient detail would help the reader to decide whether it is possible to transfer the findings of the study to other settings, times, situations, and people (Merriam, 1998; Lilcoln & Guba, 1985, 1999). Based on the review of the literature on NOS learning of teachers, the researcher provided detailed information about the relevant characteristics
of each case in the “participants” part of the methodology section. Then she presented the quotations of a particular code along with the participants’ anonymous names in the findings section so that the reader could establish the relationships between the data and characteristics of the participants to make informed decisions regarding whether the findings of this study is applicable in his or her own situation.

**Reliability.** Different from the quantitative research, reliability in the qualitative research refers to “the stability of responses to multiple coders of data sets” (Creswell, 2007, p. 210). Researchers use different ways to establish that the results of the research are reliable or dependable. In the present qualitative study, the researcher followed the suggestions of Lincoln and Guba (1999), Creswell (2007), and Yin (1994, 2003) that are described in the next three paragraphs.

According to Lincoln and Guba (1999), validity of findings cannot be obtained without the reliability of the findings. In this respect, this study provided reliable findings by establishing the validity of the findings through the aforementioned tactics or techniques (e.g., multiple sources of evidence, data triangulation, pattern matching and explanation building, member checking, peer review or debriefing, the multiple-case design, and thick description).

Another way to ensure the reliability of the qualitative research is *intercoder agreement* (Creswell, 2007). In this process, the researcher and the professor first separately and then together analyzed the data from two cases by following the aforementioned data analysis procedure. Disagreements were handled by appealing to the data and through discussions. The researcher and the professor reached one hundred percent agreement at the end.
For case studies, Yin (1994, 2003) suggested creating a case study database to increase the reliability of the findings. During this process, the researcher should organize and document the collected data in a way that other investigators can review the evidence directly. The raw data and the report of the investigator are two separate collections of documentation that go into the case study database. Both types of documentation need to go into the database in a manner that another investigator has a chance to inspect the raw data that led to the case study’s conclusions. In this study, the researcher created a database using the folder system on the computer. She collected and stored all of the data in various folders and subfolders. The database contained: (a) original questionnaires typed in Word documents, along with the researcher’s typed or audiotaped notes; (b) transcripts and audiotapes of the interviews, along with the researcher’s typed or audiotaped notes; (c) videotapes of the meetings, along with the scans of any artifacts submitted by the participants and the researcher’s typed or audiotaped notes; and (d) tabular materials that were created to record events and categorize the data. Such an organization on the computer made the raw data and their interpretations ready for independent inspection whenever requested by other investigators.
Chapter 4 Findings

Introduction

The purpose of this study was to explore to what extent and how a one-year professional development program changed the participating elementary teachers’ conceptions of the target nature of science (NOS) aspects and their beliefs about the developmental appropriateness and importance of teaching these NOS aspects. The findings of the study were presented into three sections according to the research questions. First section presents the changes, if any, in the participating elementary teachers’ conceptions of the NOS aspects. Second section presents the changes, if any, in the participating elementary teachers’ beliefs about the developmental appropriateness and importance of teaching the NOS aspects. The last section presents the participating elementary teachers’ perceptions about which components of the professional development contributed to their conceptions and beliefs about the NOS aspects.

Research Question One

The first research question investigated in this study was concerning the changes in the NOS conceptions of four elementary science teachers who participated in an academic-year long, professional development program. The professional development program consisted of two phases. The participants first received training on NOS and then they taught several NOS lessons in their classrooms during the last month of the academic year. Therefore, the changes in the participants’ NOS conceptions were examined before and after their participation in the NOS training and after their NOS teaching experience. Accordingly, the findings of the first research questions are presented in three main sections: pre-NOS training conceptions, post-NOS training
conceptions and post-NOS teaching conceptions. After presenting the findings of individual case analysis on each of these three occasions, cross-case analysis is provided in order to show similarities and differences in the participants’ NOS conceptions before the professional development program, after participating in the NOS training, and after teaching several NOS lessons in their own classrooms. The following figure illustrates a general overview of the presentation of the findings regarding the first research question.

![Diagram](image)

*Figure 3. The overview of the presentation of the first research question findings.*

**Pre-NOS Training NOS Conceptions**

This section presents the findings obtained from the individual and cross-case analyses of the four participants’ NOS conceptions at the beginning of the professional development program.
Francine’s Pre-NOS Training NOS Conceptions

At the beginning of the professional development program, I clearly identified Francine’s conceptions about the empirical, tentative, inferential, creative, subjective, and socio-cultural NOS and the myth of the scientific method.

Francine held a naïve NOS conception by connecting “the so-called scientific method” and experimentation. During the interview, Francine mentioned how she taught “the scientific method” by doing the classic paper towel absorbancy experiment as an example in her classroom.

For example, we were talking with my kids about The Scientific Method right now. I showed them five different types of paper towels. If you go to Costco and if you see five different brands, what questions come up to your minds? You know, like which brand is the best? Which one has more rolls? Which one has more sheets? Or which one absorbs the more water? Every day we have questions, but we do not know how to solve them [pre-NOS interview].

Even though she acknowledged the role of observation and studying the work of other scientists during the interview, she mainly considered experimentation as a primary route to doing science. Francine thought that scientists use experimentation in 99 percent of the time. She also held a conception that experiments can provide decisive evidence to prove an idea right or wrong, but when I probed her further during the follow-up NOS interview she changed her wording from “proving an idea right or wrong” to “supporting or revising an idea with empirical data.”
Francine appeared to have seemingly informed tentative NOS conceptions at the beginning of the program. When she was asked about the tentative NOS during the interview, she acknowledged that scientific knowledge might change. However, she seemed to feel insecure about her ideas because she was not able to provide any example because of her poor science background.

Francine: Actually, this was one of the questions I struggled a lot. I wrote it down [on the pre-NOS questionnaire] “I think it might change but I am not sure.” I really I don’t know the answer.

The researcher: What makes you feel some troubles in terms of answering?
Francine: I think it changed, but I do not have enough knowledge to give an example because I really do not know. I think about what changed or what did not change. I did not study history of the scientific theories. I do not have that knowledge to answer this question [pre-NOS interview].

When Francine was asked how scientists determined the structure of an atom, she felt that she did not have the appropriate content knowledge to answer this question. In response to this question, she provided the most typical uninformed answer regarding the inferential NOS: “Scientists did some research and they tried to use microscopes to see what it contains exactly. And as much as technology allows them to see what is inside, I think, they come up with the ideas” [pre-NOS interview].

In her both questionnaire and follow-up interview, Francine acknowledged the importance of creativity in science, but the examples she provided about creativity came from her own science teaching rather than the scientific enterprise. She talked about how
her students used creativity during classroom inquiry activities. Francine believed that longer lessons/projects give students more opportunity to use their creativity and imagination. The following excerpt underscores this point.

…when you said data collection if this is a longer of time, if you are working with insects in one island and if you are going to work for a month, of course you need to use your imagination and creativity during that data collection. But if this is just one minute, I do not think so. Depends on the length of the experiment, I think [pre-NOS interview].

When we asked Francine to elaborate on her ideas about the creative NOS aspect, her creativity example came from a classroom engineering activity rather than authentic science example. During the interview, she explained how her students used their creativity to come up with different bridge designs. This seemed to indicate that Francine thought that creativity and imagination were equally important in both science and engineering contexts.

As for the subjective NOS aspect, Francine acknowledged that scientists could come up with different explanations by looking at the same evidence. She attributed the subjectivity to personal and socio-cultural factors by failing to point out the theoretical subjectivity as seen in the following excerpt.

It is possible even though they have same data and experiments. Scientists’ personal views will affect the conclusion [pre-NOS questionnaire].
Like our personal beliefs, our cultures, the way we were raised, knowledge, and also everybody have different multiple intelligence... Since we are human and each human is unique, it affects the way we see the things [pre-NOS interview].

The above excerpt illustrates that Francine had ideas about the socio-cultural NOS aspect. However, she was not able to explain her ideas about the socio-cultural NOS in details and with appropriate examples.

Overall, I observed that Francine was *not confident* in her conceptions across the NOS aspects. For example, when Francine was asked whether scientific theories change, she responded, “I think it might change, but I am not sure” [pre-NOS questionnaire].

**Anna’s Pre-NOS Training NOS Conceptions**

Anna’s NOS conceptions identified from pre-NOS questionnaire and interview involved the empirical, tentative, creative, and subjective NOS. I was not able to find explicit statements about her inferential NOS conceptions.

Anna acknowledged the importance of empirical evidence in justifying theories. She seemed to distinguish between two types of empirical evidence: observational and experimental. However, Anna placed experimental evidence at a higher status than observational evidence. She thought that observational evidence can support scientific theories, but experimental evidence can “prove” scientific theories: “I think making observation as part of an experiment. I think maybe some scientific theories can be seen just by observing without proving.” [Pre-NOS interview]. This indicates that Anna held multiple conceptions about the role of evidence in the justification of scientific knowledge.
Anna’s hierarchical empirical NOS conceptions seemed to influence her tentative NOS conceptions. She thought that if the technology ensures “correct” data collection scientific knowledge that can be “proven” with experimental evidence does not change. However, other scientific knowledge that can’t be “proven” can change with the availability of new evidence and technology. The following excerpt reflects Anna’s conflicting tentative NOS conceptions.

Not all kinds [of scientific knowledge] can be proven with absolute certainty because you know there are scientists throughout time that said I know this is true and this is my proof, but then 10 years later they find different evidence and everything changes...I believe this is how it happens. They try to do experiment to try to prove that, but I don't think that we've always had the correct technology to get the correct information too. So, I think as technology improves they will be able to prove or disprove something that they believe before [pre-NOS interview].

Unlike empirical and tentative NOS conceptions, I was not able to fully tap into Anna’s inferential NOS conceptions. On her pre-NOS questionnaire, Anna stated that scientists make an “educated guess” to figure out what an atom looks like. During the follow-up interview, despite my further probing, she was not able to elaborate on her written response. She made a very short statement about how scientists determine the structure of an atom: “They can’t see it. I mean it can’t be seen. So, it has to be tested in some other ways, but they do with electricity or something.” [Pre-NOS interview]. It seemed like Anna’s lack of science content knowledge hindered my ability to assess her inferential NOS conceptions.
Anna seemed to acknowledge the role of creativity in selecting different data collection methods and in interpreting data. However, in both questionnaire and interview she did not provide examples of how scientists might use creativity and imagination during scientific investigations. The following excerpt illustrates Anna’s conceptions of the creative NOS.

Do they use creativity and imagination during and after data collection? I wouldn’t see they could not. I mean data collection they have to use some creativity because you don’t collect data in the same way all the time. There is creativity in that, and also again as I said after data collection imagination is individual to each person. So, I think how you would interpret some of that data might be based on your creativity and imagination [pre-NOS interview].

Anna seemed to have fluid conceptions of the subjective NOS. She acknowledged that people’s prior experiences influence their data interpretation, but she also believed that scientists could reach into a consensus with additional information. Later, she also questioned whether scientists would ever get enough information to reach into an agreement. The following excerpt underscores the lack of clarity in Anna’s subjective NOS conceptions.

Anna: I think it [scientists’ reaching at different conclusions by looking at the same set of data] can be, but I can’t really say specifically how I think that it could happen…I don’t know. Because there is no solid answer, I feel like they only got bits and pieces...because there is not enough information, they permanently, concurrently say yes, this is it.
The interviewer: So, do you think if they collect more information or enough information in the future, do you think they will agree?

Anna: I don’t know. It might or maybe not. I don’t know if there is ever gonna be enough information for them to agree because I don’t think anything is ever that certain. I mean there are certain things that are certain but I don’t know about this one [the disagreement about the state of the universe] [pre-NOS interview].

**Nancy’s Pre-NOS Training NOS Conceptions**

At the beginning of the professional development program, I clearly identified Nancy’s empirical, tentative, creative, subjective, and social NOS conceptions. However, I was not able to find explicit statements about the inferential NOS and the myth of the scientific method in her pre-NOS questionnaire and interview. It is noteworthy that Nancy explicitly expressed her lack of confidence in completing the NOS questionnaire and interview because she was new to science teaching.

Nancy acknowledged the role of empirical evidence by stating that scientists need to prove or disprove their hypothesis by appealing to data, but she believed that this evidence mostly come from the experiments.

Not all scientific knowledge may need experiments, but most will initially need them. For example, when Sir Isaac Newton discovered the law of gravity, he had to test out his hypothesis using experiments to see if what he believed to be true was [pre-NOS questionnaire].

When I further probed Nancy during the interview about whether scientists could use other ways to develop scientific knowledge, she again failed to point out the role of
observation in science: “I think that there is probably other ways, too. For instance, they can use information or data gathered by other scientists…they are not necessarily going to perform all experiments themselves [pre-NOS interview].

At the beginning of the professional development program, Nancy appeared to have an informed view of the models in science by stating “while scientific models (used a lot in this instance) are useful in the study of science, they are not necessarily copies of reality” [pre-NOS questionnaire]. However, Nancy was not able to elaborate on how scientists use their observations to come up with models. When I probed Nancy how scientists come up with the model of solar system, she just mentioned “through space exploration with amazing telescopes” [pre-NOS interview]. In other words, Nancy failed to mention that scientific models (i.e., the atom and solar system models) are inferences made by scientists based on their observations of the natural world.

Regarding the tentative NOS, Nancy thought that both scientific models and theories could be improved or changed with the improvements in technology or new measurements. However, she failed to mention how scientific theories or models could be revised with the new interpretation of the existing data. The following excerpt illustrates Nancy’s conceptions of the tentative NOS.

Nancy: Yes, scientific theories can change. Columbus thought that the world was flat and then it was found out to be round [pre-NOS questionnaire]… I mean things that were thought to be true for a long time can even be improved upon or changed because of new technology.

The researcher: How do you think scientific knowledge can change in addition to improvements in technology?
Nancy: Well, I mean as time goes by, you have all this previous knowledge to build upon and to lean information on. The more you have, the more you have to work with [pre-NOS interview].

At the beginning of the professional development program, Nancy seemed to have limited conceptions regarding the creative NOS. On one hand, she thought that scientists use their creativity and imagination before and after data collection in coming up with theories and processes. On the other hand, she believed that scientists do not need to use imagination and creativity during data collection because “collecting data is more straightforward” [pre-NOS interview]. This seemed to be consistent with her view of science as more procedural. The following excerpt illustrates Nancy’s conception of science as being more procedural than creative.

Nancy: Science, I think, is more like you have a set of steps that you are going to perform. So, it is like you are going to do A, B, C, D and in that particular order. With art, you are not going to do it the same ever time because you have a variety of materials that are going to be subject to the artist’s interpretation of how they want to use those materials.

The researcher: So, do you think that all scientists go through this kind of definitive steps?

Nancy: They don’t always have the same steps because it depends on experiment, but there is more of a straightforward set of steps that they follow [pre-NOS interview].
Nancy held inconsistent conceptions regarding the subjective NOS at the beginning of the professional development program. On one hand, she acknowledged that scientists’ prior knowledge and experience could influence the way they interpret data. On the other hand, she underscored that scientists need to reach into a consensus about the issue by appealing to the same data in order for any of their opinions to be considered as scientific knowledge. The following excerpt underscores how Nancy viewed the subjective NOS.

I think for me, for it to really be scientific, considered scientific knowledge, it should be something, that is, a consensus between multiple scientists who have looked at the data and have come to a consensus that, yes, that’s what they believe to be true. Otherwise, I mean, if you have all these different astronomers that are reading the same set of data, and they’re coming up with different ideas about what’s going to happen, it’s an opinion [pre-NOS interview].

In addition to scientists’ background knowledge and experience, Nancy seemed to acknowledge the role of peer influence in doing science. This indicates that Nancy had surface level ideas about the social NOS aspect. It seems like her preliminary social NOS ideas were linked to her subjective NOS ideas.

**Andy’s Pre-NOS Training NOS Conceptions**

At the beginning of the professional development program, I clearly identified Andy’s empirical, inferential, tentative, creative, subjective, socio-cultural, and bounded NOS conceptions.
Regarding the empirical NOS, Andy emphasized that scientific knowledge is based on both experimental and observational evidence. He stated that empirical evidence is used to “prove or disprove” hypotheses or theories in science, but he did not believe that empirical evidence can absolutely determine whether a hypothesis or theory is correct. He used the terms “prove and disprove” in the sense of testing an idea. The following excerpt underscores his empirical NOS conceptions.

I think science is sort of that trying to understand the universe or our life and why we’re here – all that stuff with evidence that we can observe and measure ... I think that science is more about saying, I have an idea and I want to prove it with something that I can find outside in the world, you know, evidence that you can point to and support… I mean, there’s a lot of things that you could say are data that weren’t really experimental. I mean, you can record, you know, the genders and names of all the students that are in my class, but that wasn’t an experiment, but that’s still, you know, that’s still data [pre-NOS interview].

Andy’s inferential NOS conceptions were evident in his both pre-NOS questionnaire and interview responses. Any was able to elaborate on his inferential NOS conceptions by using Rutherford’s gold foil experiment.

One experiment I remember was I think they put a very thin sheet of gold or something like that and fired some atomic particles at it and found that almost all of them passed through, but a very small percentage actually reflected. So, that was one way that they decide, oh, this inner structure of an atom must mostly be empty because otherwise, you know, why would these atoms be passing directly
through and only a few of them reflecting? So, they kind of deduced that those must have been the things that hit the nucleus, the only solid part whereas the electron is just in a cloud, I guess. Um, so I think that was all I wrote here [on his pre-NOS questionnaire], but I know with current electron microscopes, we can see down to the individual atoms themselves. We can see the arrangement, you know, whether it’s uniform or not so uniform or whatever, but we can actually, you know, go inside. So, that’s been more deduced through other observations that, you know, we’ve made [pre-NOS interview].

I realized that Andy’s strong science content knowledge helped him to explain in how scientists inferred the structure of an atom in detail, though he sometimes used inappropriate terminology to express his inferential NOS conceptions. Unlike the above excerpt where he used the verb “deduce”, on his questionnaire Andy used the verb “prove” to express the same idea: “when a scientist fired particles at a thin sheet of atom, finding most passed right through, but a very small percentage bounced back, helping prove that the inside of an atom is mostly empty space”.

As for the tentative NOS, Andy emphasized that there is always a room for change in scientific knowledge. He elaborated on his tentative NOS conceptions by explaining the different ways of changing scientific knowledge. During the pre-NOS interview, Andy expressed that theories could change with the availability of new evidence through the use of the new technology.

Theories change all the time. Ancient Greeks believed in 4 chemical elements (none of which were correct). Theories change over time as scientists challenge
old theories with new ones as new evidence becomes available. New technology helps the discovery of new evidence often. If people are not knowledgeable of the current theories and understandings of the universe, they would not be able to take that knowledge to the next level. Current scientists are ‘standing on the shoulders’ of those who came before them [pre-NOS questionnaire].

During the pre-NOS interview, Andy also acknowledged that scientific knowledge could change with the reinterpretation of old theories from a different perspective as in the Newtonian versus Einstein understanding of the gravity in the history of science.

I think you go back to this sort of Newtonian understanding of gravity didn’t make sense of how gravity could affect across a distance, you know, like why should the sun keep us in orbit, you know, because really there’s no connection. There’s not like a string attached, but so then, you know, when you got further with, um, you know, like Einstein, he was able to prove that, um, you know, you have sort of the – the way that space exists, you know, gravity can, um, can affect across a distance because of the – well, I won’t get all into it, but any way, that, so yes. I mean, of course. Even something like that can change over time and we can develop a further understanding [pre-NOS interview].

In addition to the tentative NOS, Andy acknowledged the creative NOS at the beginning of the professional development program. As seen in the following excerpts, he could also provide examples for how scientists use their creativity and imagination before, during, and after data collection.
If scientists are doing an experiment, they don’t just say, well, I’m just going to do some stuff and maybe something cool will happen. They have an idea before they’ve even started. They’ve already imagined what they’re hoping to find [before data collection, pre-NOS interview].

They [scientists] have an imagination to say, oh, I think this is what’s happening. They design the experiment and go, certain parts of this could be better. I’m going to try it again [during data collection, pre-NOS interview].

A scientist needs to have a lot of imagination to look at a set of data that did not turn out as he/she expected. This imagination will help create alternative explanations to test in further experiments [after data collection, pre-NOS questionnaire].

In addition to the acknowledgement of the creative NOS, Andy also mentioned its contribution to the inferential NOS. When I probed Andy during the interview regarding how scientists came up with explanations about the structure of an atom without actually seeing it, he stated “you have to have the creative mind to go, if I see these things happening, maybe this is what is actually causing it…You have to have that creativity and vision to be able to see the larger explanation” [pre-NOS interview]. In other words, Andy acknowledged that scientists used not only their observations but also their creativity and imagination to make an inference about the structure of the atom.

As for the subjective NOS, Andy acknowledged that it is natural that more than one idea could explain the same situation at the same time as seen in the below excerpt.
Any time you look at a complex set of data, your attempt to find a pattern is going to be colored by your idea of what is happening. If you think the universe is expanding, you will look for evidence that supports that theory. When there is not enough knowledge to conclusively prove one theory over the other, debate will naturally ensue [pre-NOS questionnaire].

Although Andy inappropriately used the word “prove”, he thought that the availability of new evidence does not necessarily remove the role of subjectivity in science: “even once we get enough [evidence], that does not mean that everyone is going to agree right away. Most great scientific advancements…starts out as something that a lot of people don’t believe in” [pre-NOS interview]. In other words, Andy thought that the availability of new evidence regulates the role of subjectivity in science.

In addition to the acknowledgement of the subjective NOS, Andy also mentioned how social and cultural factors could contribute to subjectivity in science as seen in the following excerpt.

...whether the earth revolves around the sun or the sun revolves around earth, I mean, it’s tied in with all those cultural things, too where people say, well, you know, we believe this to be true. This is, you know, part of our religion, and so, we don’t want to agree or find something to be true that conflicts with that. So, I mean, you’re always going to have those cultural things that are going to both help and hurt your advancement of scientific knowledge, I guess [pre-NOS interview].
Finally, Andy acknowledged that science cannot answer all types of questions. He was able to differentiate between scientific and nonscientific questions by appealing to the existence of empirical evidence during his pre-NOS interview. The following excerpt illustrates his connection between the bounded and empirical NOS aspects.

Andy: ...they [scientists] can see that even though you might be investigating a scientific principle, you know, there are some questions that science still cannot answer. You know what I mean. Whether the universe is expanding or contracting or static, it’s hard for science. Science to answer why is the universe here in the first place, you know, that’s not really a scientific question.

The researcher: So, what kinds of questions do you think science answer?

Andy: I think science can answer question where you can observe evidence about. I mean, I think that the questions of “why” are very difficult for science to answer [pre-NOS interview].

Overall, I realized that Andy held sophisticated NOS conceptions and strong science content knowledge. He seemed confident in his NOS conceptions and science content knowledge despite his inappropriate use of terminology in certain instances.

**Cross-case Analysis of Pre-NOS Training NOS Conceptions**

The cross-case analysis revealed that four NOS aspects (empirical, tentative, creative, and subjective) consistently appeared in all of the participants’ pre-NOS questionnaire and interview data. Although all of them thought that science is empirically based, tentative, creative, and subjective, they showed varied degrees of sophistication in their NOS conceptions across these four NOS aspects. Compared to other three
participants, Andy had more consistent and sophisticated NOS conceptions across these four NOS aspects.

Across the participants, I identified five main differences. The first difference was about the inferential NOS aspect. Unlike other three participants, Andy’s pre-NOS questionnaire and interview data provided ample evidence about his inferential NOS conceptions. It looks like the question about the structure of an atom failed to tap into inferential NOS conceptions of Anna and Nancy. Except Andy, none of the participants were able to elaborate on this specific question in both questionnaire and interview due to their poor science background. They thought that they did not have enough scientific knowledge about the structure of an atom to answer this question. The second difference was related to the bounded NOS aspect. Andy was the only participant who provided explicit statements about the bounded NOS aspect. He was able to describe how scientific knowledge differs from nonscientific knowledge. The third difference was the fact that only one participant, Francine, expressed a clear misconception about the myth of the scientific method. Nancy thought that science is more procedural than art, but she did not hold an obvious misconception about the myth of the scientific method. She expressed that not all scientists follow the same steps. Other participants did not provide any evidence with regard to the myth of the scientific method in their pre-NOS questionnaire and interviews. The fourth difference was that Nancy was the only participant who seemed to have a preliminary idea about the social NOS aspect. Nancy acknowledged that peer influence could lead scientists to look at their data from a different perspective. The last difference was related to the socio-cultural NOS aspect. Only Francine and Andy provided statements indicating their conceptions about the socio-cultural NOS. Francine
made a reference to the socio-cultural NOS by just listing culture as a factor leading to scientists’ subjectivity while Andy could elaborate on how several social and cultural factors could contribute to the subjectivity in science.

**Post-NOS Training NOS Conceptions**

This section presents the findings obtained from the individual and cross-case analyses of the changes in four participants’ NOS conceptions after their participation in the NOS training.

**Francine’s Post-NOS Training Conceptions**

Francine’s NOS conceptions identified from post-training NOS questionnaire and interview involved the empirical, tentative, creative, inferential, subjective, socio-cultural, and social NOS. Unlike her pre-NOS questionnaire and interview, I was not able to find explicit statements indicating the myth of the scientific method at the end of the NOS training.

Francine continued to acknowledge the role of evidence in the development of scientific knowledge at the end of the NOS training. In addition to experimentation, she once again emphasized the role of observation in providing empirical evidence: “To have a scientific knowledge you need to have your prior knowledge, observation, and then the experiment maybe, some facts” [post-NOS training interview]. At the beginning of the professional development program, Francine called every single activity as an experiment, but then she realized her misuse of the term “experiment.” With this change in her definition of an experiment, Francine started to consider observation as important as experimentation in collecting empirical evidence, though her improper usage of experiment sometimes appeared during post-NOS training interview.
Francine started to provide explicit statements about the social NOS aspect at the end of the NOS training. In addition to the role of empirical evidence, she expressed the importance of communication among scientists in doing their work during the post-NOS training interview. Moreover, Francine was able to make a connection between social and tentative NOS aspects after the NOS training. She thought that with the help of advanced technology, scientists could make their data more accessible to other scientists across countries, which in turn might contribute to changes in scientific knowledge.

At the end of the NOS training, Francine once again acknowledged the tentative nature of scientific knowledge, but her tentative NOS conceptions were more advanced for three reasons.

First, she was able to explain how the availability of new evidence can contribute to tentative nature of scientific knowledge: “Science is a curiosity that will lead scientists to discover the unknowns about our world. Religion has certain rules and they cannot change over the time, however the facts scientists found out might change after finding new evidence and facts” [post-NOS training questionnaire]. Francine also acknowledged the role of reinterpretation of the existing evidence in explaining how scientific knowledge can change: “Everybody can interpret differently, but I don’t think that we literally can change it 100% without new evidence. People may look at the old evidence differently” [post-NOS training interview].

Second, Francine was able to elaborate on her tentative NOS conceptions by providing examples from the history of science and the professional development activities at the end of the NOS training. For instance, she used Pluto’s reclassification as a dwarf planet to support her ideas about the tentative NOS aspect: “Pluto used to be our
9th planet and now scientists say that is dwarf planet” [post-NOS training questionnaire].

During our NOS training Francine connected Pluto’s reclassification as a dwarf planet to the tentative NOS aspect because she was teaching solar system in her own classrooms. It looks like she was able to identify relevant NOS conceptions in her own science content by using her current NOS conceptual framework. Francine also used the fossil activity (Lederman & Abd-El-Khalick, 1998) to explain her tentative NOS conceptions.

I can say, but after the fossil activity because I did this one in my classroom as well, each child, remember you gave us a paper. It says the fossil fragment. You say that how the kids come up with different things. How they looked at differently and at the end he told us that we even think about it is a coral reef. So, everybody was looking differently. Like it was dinosaur tooth, maybe the spikes, or claws. I was thinking like claws, some part of the foot, but yeah I can say that fossil activity mostly helped me to understand science is like it can change [post-NOS training interview].

Third, Francine started to make connections among tentative, subjective, and socio-cultural NOS at the end of the NOS training. She thought that scientific knowledge could change not only with the availability of new data but also “who actually looked at the data” because scientists’ education, culture or gender plays a significant role in their interpretation of the data [post-NOS training interview]. In other words, scientists might bring a different perspective on the existing data based on their personal and socio-cultural backgrounds, which in turn could contribute to a change in scientific knowledge.
Francine had more sophisticated creative NOS conceptions at the end of the NOS training. She started to acknowledge that creativity is used not only during data collection but also before and after data collection. The following excerpt illustrates the change in her conceptions about the creative NOS aspect.

The researcher: Do you see any difference between your two answers [pre- and post-NOS ideas]?
Francine: I think so because it [her response on the post-training NOS questionnaire] says scientists use creativity in every step, but last time [her response on the pre-training NOS questionnaire] I said while designing experiments specifically. But now, every like not only designing experiment but also inferring, while collecting data, collecting evidence, even observing or having a conclusion. Every step scientists use their creativity [post-NOS training interview].

After NOS training, Francine also elaborated her creative NOS conceptions by talking about how creativity contributes to tentative and inferential nature of science as illustrated in the following excerpt.

Artists, I believe, when they are creative, when they use their imagination and creativity, they come up with something. They just have a final product and they are done. So, with each product, let’s say if they are drawing something, if they are painting, they always come up with a product and they are done. They don’t go back. They don’t check. They need creativity. Their creativity does not help
them to go back and revise their product. They are done, but science is different [tentative NOS connection, post-NOS training interview].

Yes, they [scientists] use creativity and imagination while they are planning, during and after experiment. Scientist’s creativity helps him to infer from his observations [inferential NOS connection, post-NOS training questionnaire].

As I expected Francine’s content knowledge about the atom did not change at the end of the NOS training because the structure of the atom was not part of the NOS training. However, her lack of content knowledge did not deter her to answer the question about how scientists determine the structure of the atom. She knew that what an atom looks like is an inference made by scientists, but she did not know how exactly scientists made that inference, but she made a connection between her inferential and subjective NOS conceptions: “even though we use the same technology, as who we are, who are the scientists affects the way of inferring the things” [post-NOS training interview].

In the context of the atom question, Francine could not elaborate on her inferential NOS conceptions. However, her inferential NOS ideas were evident when she explained the role of creativity and imagination in doing science by using the cube activity as an example. The following excerpt illustrates how Francine and her peers used their creativity and imagination to infer what is underneath the cube.

I think the cube activity I can say that. So, when we were looking at the each side, all the five sides of the cube, we are trying to figure out what we have at the bottom of the cube. What we have at the sides and we are trying to come up with the pattern. We are looking at the number. We are looking at the names, as far as I
remember. So, if we were not using our creativity we stop there. So, I don’t know how to explain it, but even while we are trying to solve what we are supposed to have on the backside, I think we are using our creativity. We were trying to come up with all possible names. We were trying to look at even and odd numbers. We were trying to look at how many letters are the words. So, we are trying to use our creativity, I believe so [post-NOS training].

In addition to the creativity questions, Francine also seized the interview question regarding scientists’ disagreement on the status of the universe to express her inferential NOS conceptions. After the NOS training, Francine started to make connections between inferential and socio-cultural and social NOS aspects: “Our inference will be affected by our culture [socio-cultural NOS], environment, education, and people we work together [social NOS].

As for the subjective NOS, Francine emphasized not only the role of scientists’ personal and cultural backgrounds but also the role of their peers in doing science at the end of the NOS training: “Science is subjective and tentative. Our inference will be affected by our culture [socio-cultural NOS], environment, education, and people we work together [social NOS]. While we are observing we use our five senses and everyone have different ways of looking things” [post-NOS training questionnaire]. Different from her pre-training subjective NOS conceptions, she was also able to elaborate on how cultural backgrounds can influence the way scientists interpret the same set of data by making a reference to two children’s books (Jenkins & Page, 2003; Young, 1992) that we used during the NOS training.
I think one of the books, *the Seven Blind Mice* and also the *What do you do with a tail like this?* Because when we see the tails I was thinking differently, all other colleagues looking differently because the things they say or the animals they describe I never see maybe in Turkey. My background does not correlate with those things. This is the most, I think, the sixth activity. I realized that how are culture, how are background affect the things we see [post-NOS training interview].

After the NOS training, I realized that Francine further explained her conceptions about the socio-cultural NOS aspect. She continued to connect the socio-cultural and subjective NOS aspects, but this time she was able to make a stronger connection. Francine provided examples of how scientists’ backgrounds such as culture, religion, and gender might lead to the subjectivity in science by influencing their data interpretation. The following excerpt indicates Francine’s connection between subjective and socio-cultural NOS aspects after the NOS training.

For the science, scientists from Turkey may look at differently dinosaur bones but scientists from another country may look at differently even if they have the same facts and data. Science is subjective and it is affected by our culture, education, or background or either being a woman and the man affect how we see the things [post-NOS training interview].

At the beginning of the NOS training, Francine provided very limited examples to elaborate on her NOS conceptions. At the end of the NOS training, however, Francine explained her NOS conceptions with more specific examples and most of these examples
came from the activities that were taught during the NOS training. Moreover, she felt more confident in answering the interview questions and her NOS conceptions regardless of her lack of science content knowledge. The following excerpt illustrates this point for the tentative NOS, but it was not limited to this NOS aspect.

The researcher: So, let’s look at your initial response for this question [After scientists have develop a theory, does the theory ever change? Explain why by giving an example]

Francine: I said I don’t know for this one. [Read her pre-NOS questionnaire response for the question]. “I think it might change, but I am not sure” See!

The researcher: How do you think your answers are different right now?

Francine: On this one [pre-NOS training questionnaire] I was just trying to fill the blank because I didn’t know any idea. I told you. I think at that time with our interview I explained to you as well. Not having a strong science background does affect. I still don’t have a strong science background, but I feel a little bit comfortable. At least I learned all those activities and working with the colleagues helped me to understand [post-NOS training interview].

**Anna’s Post-NOS Training Conceptions**

At the end of the NOS training, once again I clearly identified Anna’s empirical, tentative, creative, and subjective NOS conceptions and I was not able to find explicit statements indicating her inferential NOS and the myth of the scientific method.

Anna continued to acknowledge the importance of evidence in justifying scientific knowledge at the end of the NOS training. She cleared her misconception that
experimental evidence has a higher status than observational evidence after the NOS training. This change in Anna’s empirical NOS conceptions was evident in her pre- and post-responses about whether the development of scientific knowledge requires experiments or not. Anna, unlike her pre-response, thought at the end of the NOS training that “not every scientific knowledge can be proven through an experiment” [post-NOS training interview].

Even though I could not find any statements indicating the myth of the scientific method at the beginning of the professional development, during the post-NOS training interview Anna expressed that she no longer consider experimentation so rigid. Her revised conception about experimentation helped Anna to feel more confident that there is no universal step-by-step scientific method as seen in the following excerpt.

The researcher: Do you feel any change in your idea of what is an experiment?
Anna: Yes, I don’t feel as rigid. When we are talking about the scientific method, we have to make the list for the kids more to do the first just to teach them the structure, but now I see the experiments are not so rigid. It is not, do this, this, this, and this and go [post-NOS training interview].

After the NOS training, Anna once again acknowledged the tentative nature of scientific knowledge, but her tentative NOS conceptions were more sophisticated because of two reasons. First, Anna started to think that in addition to new evidence and technology, new perspectives could also lead to change in scientific knowledge. This change in her tentative NOS conception was expressed during the post-NOS training interview as follow: “in this one [pre-NOS questionnaire response] I talked about
‘advanced technology and discovering new information’, but as I said, sometimes we don’t have to start with new information so that would be a change.” Second, Anna made connections between subjectivity in science and tentativeness of scientific knowledge: “Actually we can think old information in a different way because it is so subjective” [post-NOS training interview].

As for the inferential NOS, I again was not able to tap into Anna’s NOS conceptions. Similar to her pre-NOS questionnaire and interview, Anna provided a typical response to the question about how scientists determine the structure of an atom. She stated “Scientists build on the knowledge of other scientists. Advancements in technology help to aid in those advancements” [post-NOS training questionnaire]. When I probed Anna to elaborate on her questionnaire response during the post-NOS training interview, she expressed her lack of confidence in what she was talking. In other words, she once again could not explain how scientists use technology and the works of other scientists to determine the structure of an atom.

After the NOS training, Anna repeated that scientists use their creativity and imagination as they select the method of data collection and interpret the data and she again could not support her creative NOS conceptions with examples. Anna seemed to hold very similar conceptions of the creative NOS after the NOS training. The only difference in her creative NOS conceptions between pre- and post-NOS training was that she started to acknowledge the role of creativity and imagination in deciding what to study. The following excerpt illustrates self-evaluation of her conceptions regarding the creative NOS aspect.
The researcher: Do you feel any of your ideas changed about the creativity in science?

Anna: You know, I think that is a part that I least understood through this whole thing was a creativity part that I did not really understand, like I understand the word creativity in all of science, but I guess I am having the hardest explaining the creativity part because maybe I don’t understand it as well as understand the other NOS aspects [post-NOS training interview].

Even after the NOS training Anna felt that she did not understand creative NOS aspect as much as other NOS aspects.

Anna seemed to solidify her conceptions of the subjective NOS at the end of the NOS training. She continued to think that scientists’ prior experiences and knowledge can influence their interpretation of the data, but this time she was able to support her conceptions of the subjective NOS with appropriate examples.

Anna: ...the way you might understand, the way something is written based on your prior knowledge and what you already experienced... like, I say there is very large crack in here. You might think wow, that is really large crack or you might think that is not a large crack. You have not seen a large crack. The large crack is like this size. You know what I mean. You know what I say because you’re used to looking at the large cracks in tables and I am just you know the little one.

The researcher: Okay, good example. Based on my prior experience, I might interpret the same crack in different ways?
Anna: Yeah, yes, that is what I am saying. So, I believe that scientists will do that also with some, umm, data that means...

I also realized that the change in Anna’s conceptions of the tentative NOS seemed to strengthen her subjective NOS conceptions. She no longer thought that additional information could necessarily lead scientists to reach into a consensus because Anna, as mentioned earlier, realized that new information or data is not the only way to change scientific knowledge. She thought that scientists could change their ideas by looking at the old evidence in a different way based on their prior experiences and knowledge.

When I directly asked Anna whether her NOS ideas have dramatically changed after the NOS training, she stated that her ideas did not completely change, but she had more confidence in her NOS ideas after the NOS training.

**Nancy’s Post-NOS Training Conceptions**

After the NOS training, I clearly identified Nancy’s empirical, inferential, tentative, creative, subjective, and social NOS conceptions. However, I did not find any explicit statements in the data indicating her conceptions about the myth of the scientific method.

Although Nancy once again acknowledged the role of empirical evidence in science after the NOS training, she no longer believed that this evidence mostly come from the experiments. This difference in her empirical NOS conceptions was evident in her pre- and post-definitions of science. Unlike Nancy’s pre-NOS definition of science which conceptualized science as being more “trial+error” through experiments, her post-definition of science included observations in addition to experiments. In other words,
after the NOS training Nancy started to see observation as an important part of science as illustrated in the following excerpt.

The researcher: So, is there any instance scientists don’t need to do experimentation?
Nancy: I can think of some. I mean, if you’re observing things in the natural world, that’s part of science. You’re not really doing experiments. You’re observing. You’re taking the data that you get from those observations and using that to form conclusions about what you’re seeing. So, I don’t think that all science requires experiments, but some definitely does [post-NOS training interview].

Nancy’s post-NOS training inferential NOS conceptions did not seem to be more sophisticated than her pre-NOS training NOS conceptions. On her pre-NOS questionnaire, she talked about the role and structure of models in science. On her post-NOS questionnaire, however, she mentioned how advanced technology helps scientists to feel pretty confident about the structure of an atom. In other words, after the NOS training Nancy come to realize that ongoing improvement in microscopes make it possible for scientists to have far more confidence in the structure of an atom. When I probed this negative change in her inferential NOS conceptions during the interview, she explicitly expressed that it was not related to the NOS training. The following excerpt indicates what was responsible for the change in her pre- and post-NOS training responses about the structure of an atom.
Nancy: I think that just over the period of time that I have been teaching, I think that I have felt a little bit that, you know, technology is probably pretty good. I would say it mostly comes from my teaching experience this year.

The researcher: Okay. So, what kinds of teaching experience make you think like that?

Nancy: Just some of the things that we have read in the book and talked about and in the videos that we have watched have made me kind of feel that way [post-NOS training interview].

After her first year of science teaching, Nancy started to believe that it is possible for scientists to make sure about the structure of an atom through advanced technology.

Nancy once again appreciated the tentative nature of science at the end of the NOS training. Although she continued to believe that new information or technology could change scientific knowledge, she seemed to solidify these conceptions related to the tentative NOS because she was able to select an appropriate NOS training activity (i.e., the Tangram activity [Choi, 2004]) that illustrated how new information could change scientific knowledge. Nancy also seemed to broaden her tentative NOS conceptions by acknowledging a new way of how scientific knowledge could change. After the NOS training, she came to realize that scientists could also change their ideas because their backgrounds might help them to reinterpret the existing data from a new perspective. The following except indicates how Nancy made a connection between the subjective and tentative NOS aspects.
I think it [the NOS training] helped me to see, you know, all the different ways of how things can change. I mean theories can change just from looking at the old information, just based on, you know, that new person has a different set of background knowledge and experience and that could totally – that’s a fresh set of eyes on that new, around the same data and that could be a whole game changer [post-NOS training interview].

At the end of the NOS training, it was interesting to note that Nancy used almost the same words to describe the process of scientific investigation. She explicitly expressed during the post-NOS training interview that she did not feel any change in her NOS conceptions related to how science and art are different. Nancy continued to believe that science, unlike art, is done in “some sort of orderly fashion”, but “you don’t have to have it in that order or do it in the same order every time” [post-NOS training interview].

Nancy explicitly expressed during the post-NOS training interview that she showed the most growth in her creative NOS conceptions. She started to more appreciate the role of creativity and imagination in science because the NOS training helped her to see that scientists use their creativity and imagination even during the data collection. As seen in the following excerpt, Nancy also felt that she provided more specific examples of how scientists use their creativity and imagination not only during data but also after data collection.

They [scientists] may use it during [data collection] by seeing what is happening and determining if something in the experiment/procedure needs to be tweaked. They [scientists] may use if after [data collection] when they are analyzing the
results of the data by trying to come up with final findings (thinking about “what
does it all mean?”) [post-NOS training questionnaire].

As for the subjective NOS, Nancy continued to believe that even if scientists look
at the same set of data they might come to different conclusions based on their personal
backgrounds. However, after the NOS training, she no longer mentioned the need for a
consensus among scientists to call opinions as scientific knowledge. Rather, she
highlighted the necessity of evidence to call something as scientific knowledge. In other
words, her empirical NOS conceptions seemed to clear her misconception about the
subjective NOS.

When I asked Nancy for which NOS aspect she showed the least growth after
participating in this NOS training, she expressed that her ideas about the social NOS
aspect did not change so much. She still thought that scientists work in teams or alone,
but she did not feel this NOS aspect as important as other NOS aspects.

Overall, I realized that Nancy seemed to improve her NOS conceptions for certain
NOS aspects by providing more specific examples and she felt more confident in her
NOS conceptions at the end of NOS training.

**Andy’s Post-NOS Training Conceptions**

After the NOS training, I again clearly identified Andy’s empirical, inferential,
tentative, creative, subjective, socio-cultural, and bounded NOS conceptions.

Andy continued to acknowledge the role of both experimental and observational
evidence in science at the end of the NOS training: “Science is a way to view the world
and try to explain how the world works… Science is developing this understanding
through evidence. This evidence can be experimental data or observation” [post-NOS
 Unlike his previous response, after the NOS training Andy was able to explain why the development of all scientific knowledge does not require experimentation. He mentioned during the post-NOS training interview that there are some disciplines in science (e.g., Astronomy or Geology) where it is impossible to do experiments because of our inability to control whatever being investigated or our short life time span. Moreover, Andy started to express his empirical NOS conceptions using more appropriate language at the end of the NOS training. He no longer used the terms “prove and disprove” to express the role of empirical evidence in science. The following excerpt underscores this language change in his empirical NOS conceptions after the NOS training.

The researcher: So, when you look at these two answers [responses for the second question on the pre- and post-NOS training questionnaires], do you see any difference in your responses?
Andy: ...the difference that I see right off is that, I guess, this is not something necessarily that I’ve been like oh, my gosh, yes, I totally know this now, and I didn’t know it before, but the idea that you can really prove or disprove something is very difficult, you know. To really say this absolutely 100% this works or this absolutely 100% does not work is very difficult, and I think that I stayed away from that idea [prove or disprove] here [on his post-NOS training questionnaire] more that like it [an experiment] is testing the theory, and you can see if they support it or if they don’t support it, but it’s kind of hard to say you’ve proved or disproved this [post-NOS training interview].
In other words, the NOS training helped Andy clarify and better articulate his empirical NOS conceptions that observational or experimental evidence are important for scientists to justify their ideas, but it does not ensure absolute certainty for their ideas.

Andy’s post-conceptions of the inferential NOS were almost the same as his pre-conceptions of the inferential NOS. He once again explained that scientists make inferences about the structure of an atom based on the results of their experiments and observations: “I think they [scientists] can go inside of it [an atom], but as far as have we seen it? I don’t think so. I think it’s just what we’ve put together based on everything else we’ve observed and you know” [post-NOS training interview]. However, this time Andy “stayed away” from using the term prove in his explanation of how scientists determine the structure of an atom because he thought that the term prove could convey to others a misconception about the certainty of scientists’ inferences, “yep, knock on wood. Got it. It is hard” [post-NOS training interview]. In other words, he better articulated after the NOS training that what we know about the structure of an atom is a tentative inference made by scientists based on the available experimental or observational data.

After the NOS training, Andy continued to explain how scientific knowledge could change with the availability of new evidence or with the reinterpretation of the old evidence from a new perspective. The following excerpt illustrates Andy’s examples from the NOS training about the tentative NOS aspect.

I would say that like the Fossils activity [Lederman & Abd-El-Khalick, 1998] where you’re looking and saying, okay, here’s your fossil and then you had to change your opinion when you looked at other people and go, oh, okay, actually, you might think that; oh, well, that sounds like a better idea. I might want to
change it. And also the *Tricky Tracks* one [Lederman & Abd-El-Khalick, 1998] was sort of similar where you’re seeing part of the story. Now, you see a bit more of the story and you may have to say, okay, actually that story is not really consistent with the new information I have. So, you have to revise your story and then, you know, further you get more information, and you have to revise your story again because maybe what made sense and was consistent with everything you had before is not consistent with what you have now [post-NOS training interview].

Andy seemed to hold very similar conceptions of the tentative NOS after the NOS training, but as mentioned earlier in the empirical and inferential NOS, he no longer used the term *prove* in his speech. In other words, Andy became aware that his usage of the term *prove* could mean that scientific knowledge will not ever change, though he did not ever consider scientific knowledge that way.

Andy once again acknowledged that scientists use their creativity and imagination before, during, and after data collection. However, Andy was better able to articulate his creative NOS conceptions with more specific examples at the end of the NOS training. For example, Andy mentioned how Mendeleev used his creativity and imagination to predict the discovery of new elements based on his periodic table. In addition to the role of creativity and imagination in making predictions, he also explained how Newton used his imagination and creativity in formulating the law of gravity as seen in the following excerpt.
Yes, it takes great creativity to pick out patterns in the data. Newton had to be very creative to explain the way that gravity acted over a distance to create a mathematical formula for it. Everyone had the observations of how the planets moved; he found the formula to explain why they moved that way when all other scientists of the time were stamped [post-NOS training questionnaire].

In addition to history of science examples, Andy also elaborated on his creative NOS conceptions by providing examples from the NOS training activities. During the interview, he explained how one had to use his or her creativity and imagination to infer what is inside the bottle during the Bottle activity.

As for the subjective NOS aspect, Andy continued to appreciate that scientists could reach at different conclusions using the same data set. When I asked Andy to comment on his pre- and post-NOS responses regarding the subjective NOS aspect, he was able to detect his misuse of the verb “prove”, “when there is not enough knowledge to conclusively prove one theory or the other [theories about the status of the universe], debate is naturally going to ensue” [pre-NOS questionnaire]. This implies that after the NOS training Andy again thought that the availability of new evidence regulates, but does not remove out the role of subjectivity in science. He further elaborated on his reasons why subjectivity takes place in science. Before the NOS training, Andy thought that scientists’ beliefs guide their study and these beliefs are influenced by social and cultural environment. At the end of NOS training, Andy continued to think that scientists’ beliefs guide their work, but he started to emphasize that these beliefs are also influenced by scientists’ personal (i.e., prior knowledge and experience) and theoretical (i.e., field of
study) backgrounds in addition to their socio-cultural background. The following excerpt illustrates Andy’s post-NOS training subjective NOS conceptions.

Let’s say your field of study is one particular aspect of this problem. You’re going to have a lot of knowledge, a lot of experience where someone else might go, oh, this makes sense. You might be able to say, actually I know because I’ve studied X, Y, and Z; that theory doesn’t actually fit. So, they’re going to lean towards something else, whereas another person might have spent a lot of their time, let’s say… I don’t know. I’m trying. It’s just not specific enough to where I can like grab on to the examples, but basically, you know, even your family background. Let’s say you’re coming from a household where they all believe in one particular religion that may slant your, you know, your views of how you interpret something because you know, you have that inside of you already, I guess [post-NOS training interview].

Andy was also able to make a connection between the subjective and creative NOS aspects after the NOS training, though this connection was not as clear as his pre- and post-NOS training connection between the subjective and socio-cultural NOS aspects. On his post-NOS training questionnaire, he explained how artists’ creativity and imagination might contribute to the subjectivity in their work: “Two artists looking at the same canvas and plate of paints may envision very different pictures” [post-NOS training questionnaire]. However, he could implicitly point out this connection between creativity and subjectivity for scientists by stating, “Science and art are similar because both require
great creativity” and “From one set of data/observation, many conclusion could be
drawn” [post-NOS training questionnaire].

After the NOS training, Andy continued to differentiate what kinds of questions
fall within the realm of science by appealing to the existence of empirical evidence. The
following excerpt illustrates his conceptions about the bounded NOS.

The researcher: I realized [in his definition of science on his post-NOS training
questionnaire] that you put why into quotation like that “science doesn’t really
answer ‘why’”. Why did you put the quotation?
Andy: Just because to show that it’s a “why” question. It’s not to answer “why,”
like in general just the questions of “why.” Why are we here on planet earth?
That’s not really a question for science, you know. Why was the universe created
in the first place? I don’t think that science can really answer that because there’s
a limit to, if you’re just looking at evidence, it’s hard to say what that would ever
be. So, I just put the “why” questions as a category [post-NOS training interview].

As seen above, Andy believed that science cannot answer the questions of “why”,
because it is not possible to collect empirical evidence to answer these types of questions.

Overall, I realized that Andy did not show a massive shift in his NOS
conceptions. He held very similar NOS conceptions after the NOS training, but he was
able to provide more specific and in-depth responses using more appropriate language
after the NOS training. It is also noteworthy that my assessment of Andy’s post-training
NOS conceptions was consistent with his own reflection about his NOS conceptions after
participating in the NOS training. The following excerpt presents an example of how
Andy explained the differences, if any, in his pre- and post-NOS training questionnaire responses.

I think I get into lot more detail here [on his post-NOS training questionnaire]. I think, in general, I was able to express myself better because I have examples to remember from, you know, going through the class and all that stuff. So, sort of similar to what I said before. The more you have talked about it [NOS], the better versed in it, you can explain in the language, the proper wording, you know [post-NOS training interview].

**Cross-case Analysis of Post-NOS Training NOS Conceptions**

Once again, I found that four NOS aspects (empirical, tentative, creative, and subjective) consistently appeared in all of the participants’ post-NOS questionnaire and interview data. Bounded NOS aspect appeared only in Andy’s post-NOS questionnaire and interview responses. None of the participants expressed any misconceptions about “the scientific method” at the end of the NOS training.

The cross case analysis yielded four major themes: (1) clarification of empirical evidence, (2) integration among NOS aspects, and (3) elaboration on NOS aspects with more specific examples, and (4) increased confidence in NOS conceptions.

First, I realized that three participants (Francine, Anna, and Nancy) started to acknowledge the importance of evidence generated by observation in addition to experimental evidence even though they only mentioned experimental evidence in their pre-NOS questionnaire and/or interviews. Unlike others Andy appreciated the importance of observational evidence both at the beginning and at the end of the NOS training.
However, Andy was better able to elaborate on the empirical NOS aspect by underscoring the importance of both observational and experimental evidence in science.

Second, I found that all participants started to make explicit connections among NOS aspects. For example, Francine made creative-tentative and creative-inferential NOS connections. She thought that creativity plays a crucial role in how scientific knowledge changes and how scientists make inferences based on empirical data. Anna was able to make a connection between subjective and tentative NOS aspects. She thought that scientists’ subjectivity inevitably leads to change in scientific knowledge. Like Anna, Nancy made a connection between subjective and tentative NOS aspects. In addition to the subjective-tentative NOS connection, Nancy also connected creative and subjective NOS aspects by stating that scientists’ backgrounds play a crucial role in forming their creativity. None of the participants except Andy mentioned bounded NOS aspect at the end of the NOS training, but he seemed to more strongly emphasize the role of empirical evidence in explaining his bounded NOS conceptions.

Third, I realized that all participants did not make dramatic changes in their NOS conceptions, but they were better able to explain their NOS conceptions with examples from the history of science and/or NOS training activities. It should be noted that participants more frequently used the NOS training activities when they elaborated on their NOS conceptions. For instance, before the NOS training Francine expressed her tentative NOS conceptions by simply stating that scientific knowledge can change. However, after the NOS training she was able to explain how new evidence and the reinterpretation of the old evidence could lead to the revision of scientific knowledge by using Pluto’s reclassification as the dwarf planet and the Fossils activity (Lederman &
Abd-El-Khalick, 1998). Anna started to use the Fossil activity to elaborate her empirical NOS conceptions at the end of the NOS training. She acknowledged that conducting investigations based on fossil observations are considered as scientific. She accepted that one does not have to conduct experiments in order to be considered scientific. After the NOS training, Nancy further explained her tentative NOS conceptions by referring to the Tangram activity (Choi, 2004). In this activity, a new piece of evidence (a new tangram piece) causes one to consider changing the positions of other tangram pieces so that they fit with each other. She drew a parallel between how scientific knowledge is revised and how the positions of tangram pieces are changed with the new piece of evidence. Andy used both history of science examples and NOS training activities to support his creative NOS conceptions at the end of the NOS training. He explained how Mendeleev used his creativity and imagination in constructing the periodic table. Andy also underscored the importance of creativity and imagination in science by drawing a parallel between how scientists use creativity and how one could use creativity and imagination during the Cube activity (Lederman & Abd-El-Khalick, 1998).

Fourth, I realized that after the NOS training all of our participants started to feel more confident in what they knew about NOS. At the beginning of the NOS training, they made statements such as ‘I don’t know’, ‘I don’t have a clear answer for this’, and ‘I am not sure about that’ on their written post-NOS questionnaires and during the post-NOS interviews. However, they made statements indicating more confidence in their NOS conceptions such as ‘I feel more comfortable in explaining my ideas’ and ‘I feel my ideas are strengthened’ at the end of the NOS training.
These four major themes reflect both similarities and differences across cases in terms of participants’ NOS conceptions, but altogether these four themes indicate that all participants made noteworthy positive changes across the empirical, creative, subjective, and tentative NOS aspects.

**Post-NOS Teaching NOS Conceptions**

This section presents the findings obtained from individual and cross-case analyses of the changes in four participants’ NOS conceptions after teaching several NOS lessons in their classrooms.

**Francine’s Post-NOS Teaching Conceptions**

Francine had one primary and one secondary third grade classrooms. In her primary classroom (the so-called “home classroom”), she was responsible for teaching science, math, and social studies. Every day, she had to switch her students in the home classroom with the students of another third grade teacher at the school. As her students were learning reading and writing in the other teacher’s classroom, Francine was teaching science and math to that teacher’s students in her classroom (i.e., in her secondary classroom). Among the four elementary teachers, Francine was the only teacher who did not want me to observe her secondary classroom because she planned to use this class to practice her NOS teaching and she invited me to observe her primary classroom to show her best NOS teaching performance.

Except for the *Seven Blind Mice* (Young, 1992) and *Tricky Tracks* (Lederman & Abd-El-Khalick, 1998), Francine used all of the NOS activities from the NOS training in her two classrooms. She did not teach the *Seven Blind Mice* (Young, 1992) because of the time constraints and the *Tricky Tracks* (Lederman & Abd-El-Khalick, 1998) because of
her absence at the time of that activity. However, she insisted on and did teach the *Fossil* activity (Lederman & Abd-El-Khalick, 1998) during the NOS training, when she was not supposed to do. She did not wait the completion of the NOS training because the science content of this NOS activity matched with her curriculum at that time. After the NOS training, Francine taught four NOS activities in her two classrooms: the *Bottle* activity, the *Tangram activity* (Choi, 2004), the *Cube* activity (Lederman & Abd-El-Khalick, 1998), and *What do you do with a tail like this?* children’s book (Jenkins & Page, 2003).

The following paragraphs describe Francine’s post-NOS teaching conceptions relative to her pre- and post-NOS training conceptions.

After learning about NOS and teaching several NOS lessons in her classrooms, Francine continued to acknowledge the role of evidence in science: “The scientific knowledge, I think, is based on more evidence and data. The opinion depends on our prior knowledge or what we hear from people, what we read, but opinions don’t always depend on the data” [post-NOS teaching interview]. Unlike her post-NOS training, but similar to her pre-NOS training interview, during the post-NOS teaching interview Francine thought that most of the time experimentation is required to do science. This might be related to her misuse of the term *experiment* because Francine reverted back to call hands-on activities an experiment. For instance, during the post-NOS teaching interview Francine considered the *Cube* activity (Lederman & Abd-El-Khalick, 1998) as an experiment because students did observations and then made inferences.

I think that [the *Cube* activity] is experiment because they try to find the pattern and then they try to see, depending on working, and they discussed together and they tried to come up with logical reasoning. I think even though it is not a
blowing up the things, something, but still experiment I think so. They were collecting data. They were making observations and then they were comparing their data together and I think that is an experiment [post-NOS teaching interview].

As seen in the above excerpt, NOS teaching experience could not help Francine to solidify her post-NOS training conception that not every hands-on activity was an experiment.

Teaching NOS seemed to solidify Francine’s social NOS conceptions. She once again acknowledged the value of collaboration and communication in science and made a connection between social and tentative NOS. During the post-NOS teaching interview, Francine mentioned how her students started to change their ideas after hearing and listening their peers’ different ideas about the same phenomenon.

Francine continued to acknowledge the tentative nature of science after teaching NOS in her classrooms, but she solidified her tentative NOS conceptions: “…everything was just like blowing, I mean in my mind, but it is not like, it is more concrete right now and I am believing this right now. I can say that it [teaching NOS] helped me build a more concrete belief” [post-NOS teaching interview]. This change that Francine expressed in her tentative NOS conceptions was visible in her definitions of science. During the post-NOS teaching interview, Francine stated that she started to view science as “trying to figure out” problems rather than “solving” problems and underlined that “you do not have to solve the problems. You need to do what you can with the current data or knowledge…the logical conclusion you come up may not be the solution actually. This is the best solution so far” [post-NOS teaching interview].
After the NOS training, Francine once again elaborated on her tentative NOS conceptions by relating it to the subjective NOS. However, this time she better explained the connection by providing several examples as seen in the following excerpt.

I think most of the activities, like a black Bottle activity, even when you did this one to us, we did not know what is inside and then I was so curious, I wanna know, and I could not find a solution. So, I don’t want my kids the same way, but I told them it might be the solution. But we have like ten different solutions. It might work. It might not work. We need to try. So, I think the same everything there is not, especially my students they did not come up with one solution for the cube activity or the tangram, all of them had tons of different solutions. It makes sense when you look at them very carefully. So, there is not only one solution. What is a solution to me right now, what is the best logical reasoning at that moment with your knowledge, with your data, I think so [post-NOS teaching interview].

Francine made a generalization across different NOS training activities that scientists might come up with multiple plausible explanations by looking at the same set of data. This meant to her that there would always be room for change in scientific knowledge.

In addition to the influence of subjectivity on tentative NOS, Francine also mentioned how having an understanding of tentative NOS could help her students to develop more sophisticated subjective and social NOS conceptions: “I think when they learn science is tentative, they will learn like the value of different point of views, value
of collaborating, the value of learning from others. It is going to help them not only as a scientist but also as a person” [post-NOS teaching interview].

Once again Francine emphasized that her lack of background in the physical science prevented her to explain in detail how scientists determined the structure of an atom: “I don’t like the physical science... I think that is the reason like even while I am teaching, I did the physical science at the end... I am sorry that I never be interested in those concepts” [post-NOS teaching interview]. Therefore, she continued to provide a very basic response that scientists should use some kinds of technology together with previous knowledge or findings to determine the structure of an atom. Even though Francine could not still elaborate on how scientists inferred the structure of an atom based on evidence, she came to realize after the NOS teaching experience that what we know about the structure of an atom is the best explanation, and thereby, subject to change in future.

The researcher: So, how certain do you think scientists about the structure of the atom? What kinds of evidence do you think scientists use to come up with this structure?

Francine: I think at this moment that is the best explanation of the atom, but scientists in the future might change it with the new technology, with the new knowledge. This is the best they can come up with so far.

The researcher: So, how do you think they come up with this best idea about the structure of the atom?

Francine: I don’t know [post-NOS teaching interview].
As seen in the above excerpt, I could not tap into Francine’s inferential NOS conceptions using the atom question. However, her inferential NOS conceptions were again evident when she talked about the interview question that aims to measure the role of creativity in science. During the post-NOS teaching interview, she explained how her student used his creativity and imagination to infer what is underneath the cube by making a parallel between the cube pattern and the letters and numbers on telephone keys.

Do you remember how I mention about the Cube activity? So, they have seen the pattern like while they were observing the pattern, they were looking at the bottom numbers and top numbers and names and girl name, boy name. Do you remember one of the kids stand up and wanted to form [a pattern] he was trying to tell me that I did not understand first because I never thought that the 5 keys K, L, J, whatever. So, while collecting data they were using their creativity and then when they were trying to come up with the conclusion they were using their creativity as well. Every step [post-NOS teaching interview].

In addition to the connection between creative and inferential NOS, NOS teaching helped Francine to solidify her post-NOS training conception that scientists use their creativity and imagination not only during data collection but also before and after data collection. The following excerpt underscores the influence of NOS teaching experience on Francine’s creative NOS conceptions.

I was thinking that scientists use their creativity, but it was just knowledge and it was not really the big. It was like you have an idea, but it is not, you don’t have the columns to support that. Now, seeing my kids how they use their creativity
helped me to build, I think, strengthen my understanding, I can say [post-NOS teaching interview].

Since the beginning of the professional development program, Francine appreciated that scientists may come up with different explanations by using the same set of data. Her pre-subjective NOS conceptions simply included a list of several personal background factors leading scientists’ having multiple conclusions. Her post-subjective NOS conceptions (both after NOS training and NOS teaching) were notably different because she was able to explain how these personal background factors could cause scientists to reach into different conclusions. In the following excerpt, Francine elaborated on how scientists’ prior experience could affect their conclusions using the *Tangram* activity (Choi, 2004) she implemented in her NOS teaching.

...when I gave them tangram pieces, it was exactly the same pieces, but some of them could not come up what a solution, but I remember one of the kids said, “I like solving those types of puzzles”... It helped him to figure out quickly because he said “I have experience with this”. So, but I have some kids like I have some girls-like girly girly girls-like they don’t do puzzles, they don’t. They have lack of experience because we look it, but we did not see the patterns; we did not know how to fit into new evidence, new pieces. So, I think that definitely affects how I see the things [post-NOS teaching interview].

In addition to scientists’ background knowledge and experience, Francine started to realize the role of scientists’ creativity in reaching at multiple conclusions after teaching several NOS activities in her classrooms as illustrated in the below excerpt.
I was telling them [my students] you were like a little scientist. What you are doing actually the scientists are doing. I keep saying that… I was asking them the same questions “how possible?” You have exactly the same pieces. You are observing the same pieces. How [is it] possible you can come up with different explanations? Even the kids were saying that because our creativity is different. You are different person. So, our background is different, our knowledge is different. So, I think that is how I [would] explain [post-NOS teaching interview].

Moreover, Francine mentioned how socio-cultural and social factors could also lead to scientists’ subjectivity: “scientists’ social and cultural backgrounds, their gender, or their prior knowledge and also whom they communicate, whom they collaborate together affect the way of they see the things, I think so” [post-NOS teaching interview].

After the NOS teaching experience, Francine seemed to both elaborate and solidify her conceptions of personal subjectivity in science, yet she was still unable to point out the theoretical subjectivity in science.

Overall, Francine did not show a big shift in any of her NOS conceptions after teaching these ideas about science in her classrooms. However, she was able to use this teaching experience as a way to strengthen her NOS conceptions. The following excerpt underscores the overall influence of NOS teaching experience on Francine’s NOS conceptions.

The researcher: So, can I say, in general, teaching is kind of a way for you to see your ideas are correct rather than change your ideas?
Francine: yeah, exactly... I believed we will benefit from that but I was not sure how much we would benefit. So, at the end I saw that my students benefit a lot and I benefit a lot because all those terms [NOS aspects] we were talking were not concrete for me, but now it is more concrete [post-NOS teaching interview].

In addition to solidifying her own NOS conceptions, the NOS teaching experience seemed to help Francine develop some ideas about how to better teach this content to her students. Francine used to teach “the scientific method” at the beginning of each academic year in her previous science teaching. After her NOS teaching experience within the course of this study, Francine realized that it would be better to teach her students “nature of science: how science works actually” instead of “the scientific method” at the beginning of the next academic year.

**Anna’s Post-NOS Teaching Conceptions**

Like all teachers at the school, Anna had two classrooms. She was responsible for teaching science and math to these two fifth grade classrooms. Except for *Seven Blind Mice* (Young, 1992) children’s book and *Tricky Tracks* (Lederman & Abd-El-Khalick, 1998) Anna used all of the NOS training activities in her two classrooms. When I looked her NOS teaching planning sheet I realized that she excluded these two activities because the reading level of the book was too low for the fifth graders and she did not have a chance to observe how *Tricky Tracks* was taught due to her absence. Before starting to teach these five NOS activities, Anna introduced the NOS aspects to her students by preparing a PowerPoint presentation together with a worksheet to fill as watching the videos on the presentation. It should be noted that this introductory presentation and/or
 worksheet were also used by the other participating teachers at the beginning of their NOS teaching. After a brief summary of Anna’s NOS teaching in her classrooms, the following paragraphs describe her post-NOS teaching conceptions relative to her previous NOS conceptions.

After teaching several NOS lesson in her classrooms, Anna strengthened her empirical NOS conceptions because she observed that her students sometimes did not base their conclusions on some kind of evidence. The following excerpt illustrates Anna’s classroom observation and reflection on the importance of empirical evidence in scientific knowledge.

Again when you are talking to the kids and teaching these lessons, they are giving you answers, but you are asking them “why?” and if they cannot come up with “why”, then that means that it is really basically their opinion, but if they make a connection to whatever this we were doing, they are basing it on some kind of evidence. So, I think for me that is kind of what strengthened my thoughts on this whole thing. If they are able to give me feedback about oh, this is what we saw and this is what we did then okay, that could be more scientific knowledge for them other than what you think. What was in the bottle is scorpion. Why? Why did you think it is scorpion? Right, you know, there was no evidence to that. So, that was the difference for [scientific knowledge and opinion] [post-NOS teaching interview].

Teaching NOS also helped Anna to solidify her post-NOS training conceptions regarding the role of both observational and experimental evidence in science: “I know observation
is not necessarily an experiment. So, something is based on observational; something is based on testing data. So, I don’t think all [scientific knowledge] require experiments. No” [post-NOS teaching interview].

After teaching NOS, Anna continued to believe that scientists determine the structure of an atom by building on the data or knowledge of prior scientists: “You can’t see the whole atom. So, it is based on, I don’t know…it is just based on what prior scientists have, what kinds of data they come up. I don’t know specifically like where they got this information” [post-NOS teaching interview]. She once again could not elaborate on how scientists inferred the structure of an atom based on their observations and prior knowledge. In other words, I still could not tap into Anna’s inferential NOS conceptions via the question regarding the structure of an atom. When I probed Anna to think of some NOS activities in her teaching, she was able to draw a parallel between how scientists determined the structure of an atom without actually seeing it and how her students determined what is inside a black bottle without actually looking inside. During the post-NOS teaching interview, Anna could explain that her students used their prior knowledge and experience to make an inference about what is inside the bottle. Moreover, she was able to express her inferential NOS conceptions when she was talking about What do you do with a tail like this? (Jenkins & Page, 2003) children’s book as well. Different from the Bottle activity, she came to realize the role of creativity in making an inference about the animal by observing just a small part of it: “in the book [What do you do with a tail like this?] all they saw was a part of an animal and they had to use their imagination, prior knowledge, and experience to figure out the animal” [post-NOS teaching interview].
As for the tentative NOS, Anna was able to solidify her post-NOS training conception that not only new information or technology, but also a new way of looking at the existing data might change scientific knowledge. As seen in the following excerpt, Anna explained how tentative NOS aspect was present in one NOS activity. She stated that students constantly revised their ideas/inferences about what is inside the bottle after they shared their ideas with their friends.

when we were doing the bottle activity, the kids were coming up with things like there is magnet in the bottle, but then other children were coming and then we were talking about well, if there is a magnet there has to be metal somewhere, you know, and there is none on the string. So, then other children were coming up with more appropriate theories and then you could see how the rest of the room or the others almost adapted that theory...They are sharing their ideas like that changed the way of thinking and I think, I am not the where I am looking for. They realized that some of their views could be impossible, but some of the other views could be possible. So, this is kind of what makes more sense to them [post-NOS teaching interview].

Anna acknowledged that scientists use their creativity and imagination in selecting data collections methods and interpreting data since the beginning of the professional development program. However, it was at the end of her NOS teaching when she was able to explain in details how scientists use their creativity and imagination in their work. The following excerpt includes Anna’s examples for the role of creativity and imagination in data collection and interpretation.
They [scientists] use their creativity to figure out how to collect data. I mean, when I was showing the kids those videos, that one video did come to my mind all the time when I talk about this [creative NOS] to guide them. He needs to collect moths for his investigation of whatever he was doing and instead of running around with that net, he figured that he would put the light in the middle of the sheet and they would come to him. So, he is using his creativity in obtaining the moths for the experiment and collecting the data that I would say. And after [the data collection], when you are interpreting the data, there is some creativity in because you don’t have the all answers. So, you’re got to. Not everything is black and white. So, you are got to be able to make some inferences based on creativity, that I would say based on your imagination what you think could be happening [post-NOS teaching interview].

In addition to elaborate on her creative NOS conceptions, Anna acknowledged that the NOS teaching experience also helped her to clarify the difference between scientific and artistic creativity. She came to realize after her NOS teaching that scientists’ creativity and imagination will be bounded by empirical evidence.

You need to use imagination in science. Not everything is black and white. So, you have to be able to be imaginative and creative in coming up with different theories and what the data means. All parts of science have to be creative, but science is linked to evidence. Art is creativity. It is all yours. You are not using other people’s information or building off anything. It is just a personal work that you have [post-NOS teaching interview].
Unlike her previous creative NOS conceptions, Anna was able to express her creative NOS conceptions by providing concrete examples and by connecting creative NOS aspect to empirical NOS aspect. She also connected creative NOS aspects to inferential NOS aspects as mentioned earlier.

Anna continued to acknowledge that scientists’ prior knowledge and experience might lead them to reach at different conclusions based on the same data set. Similar to her post-NOS training conceptions, at the end of her NOS teaching Anna was able to provide an example that supported her subjective NOS conceptions. As seen in the following excerpt, Anna explained in detail how her students came up with different living organisms by observing the same fossil fragment because of differences in their prior knowledge, experience, living environment, and culture.

When we did the paleontologist video and stuff like that, I guess, the difference would be some of the kids tilted that fossil and they created totally different things and they had exactly the same evidence. We got birds’ beaks. We got claws. All of that was based on, I think, for them prior knowledge, prior experience, what they have been seen before. I guess culture would come in if just say we found this fossil somewhere in the rainforest, you know, different part of the world. Their opinions are going to be different on what part of is because what they used to live in their environment. So, as opposed to being found in the dessert, their opinion is going to be different because whatever they used to live in their environment. So, that is what I am trying to say is depending on their environment, their prior knowledge and experiences, the culture where they live
and all other stuffs can affect what they think the outcome would be [post-NOS teaching interview].

At the end of NOS teaching, Anna also believed that scientists’ subjectivity was bounded by the amount of available evidence. However, in contrary to her pre-NOS conception, this did not mean that having more data could eliminate the influence of subjectivity in data interpretation as seen in the following excerpt.

Anna: I think that because there is not enough information to really be able to tell exactly what is happening, people are taking the information that they have in making inferences. Because there is not enough information, it can go either way. If they had more evidence or a longer period study, they would be able to see the pattern better, I guess. May be there is not enough specific way to measure.

The researcher: So, assume that we have enough information about the topic. Can scientists still disagree?

Anna: yeah because people have different experiences in mind. It can be based on the million things. Be based on culture. Could be based on where they live. It can be based on what they have learned already [post-NOS teaching interview].

Anna started to develop her ideas about the socio-cultural NOS after her NOS teaching. She acknowledged that scientists’ culture might also lead to subjectivity by influencing their data interpretation. However, she was not able to explain her ideas about the socio-cultural NOS in details and with appropriate examples.

In addition to the socio-cultural NOS, Anna started to emphasize the social NOS at the end of her NOS teaching with the acknowledgement of the scientific community.
She was also able to make a connection between social and tentative NOS aspects; even though this connection was weak. She acknowledged, “a theory could be adapted by the scientific community” [post-NOS teaching interview], but she did not elaborate on how scientific community contributes to the tentative NOS. Additionally, she mentioned how her students revised their ideas about what is inside a black bottle after hearing different ideas from their peers. However, she did not draw a parallel between her students and the scientific community. When I asked Anna the overall effect of the NOS teaching experience on her own understanding of NOS, she expressed that teaching enriched her NOS conceptions:

Teaching strengthens your ideas because, I think, when you learn something and then you are teaching, you are just reinforcing what you have learned, umm, but also the kids, when you teach some to the kids, their feedbacks also give you new ideas, too. You learn from them also as much as, especially when you are learning something new [post-NOS teaching interview].

Her post-NOS teaching reflections showed similarities with my own assessment of her NOS conceptions. I think that Anna solidified her NOS conceptions after teaching NOS in her classrooms because she elaborated on her post-NOS teaching conceptions with more conceptual clarity and without me resorting to more clarification questions. She started to reflect on her teaching from the NOS perspective. For example, she realized that the directions that she provided to her students for science fair projects could implicitly convey a misconception about “the scientific method.” Through her personal
reflections, she also noticed that she was presenting science concepts as final products not as a body of knowledge that can be revised in the future:

You teach certain ideas about science, like this is what an atom looks like. When you test students, you say draw me a picture of an atom and it is certain this is what it looks like, period. So, this idea that this is what we think it looks like for now is what I did not teach as much [post-NOS teaching interview].

**Nancy’s Post-NOS Teaching Conceptions**

At the time of the study, Nancy started to teach science to two fifth grade classrooms at the school. It was her first year of both teaching fifth grade and science. She started her NOS teaching with an introductory lesson on NOS aspects. She borrowed Anna’s PowerPoint presentation and worksheet to use in her introductory NOS lesson. After introducing the NOS aspects to her students, Nancy used the *Bottle* activity, *Seven Blind Mice* (Young, 1992) and *What do you do with a tail like this?* (Jenkins & Page, 2003) children’s books, the *Tangram* activity (Choi, 2004), and the *Cube* activity (Lederman & Abd-El-Khalick, 1998) in her two classrooms. She excluded *Fossils* and *Tricky Tracks* activities (Lederman & Abd-El-Khalick, 1998) from her NOS teaching. I realized during my classroom observations that Nancy’s NOS lessons were frequently interrupted because of students’ behavioral problems. The following paragraphs describe Nancy’s NOS conceptions at the end of her NOS teaching compared to her pre- and post-NOS training conceptions.

Nancy acknowledged the role of empirical evidence in science since the beginning of this study. Teaching NOS helped Nancy to solidify her post-NOS training
conception that observation was as important as experimentation in science as seen in the following excerpt.

I don’t think that every single scientific knowledge that has been developed over the years has required an experiment. I think that a lot of them do. A lot of types of science do, but I mean there are types of science that really don’t need to have experiments, like biology or botany. You don’t always do experiments when you are identifying plants. I mean it is a classification [post-NOS teaching interview].

The aforementioned excerpt indicates that after teaching NOS, Nancy was able to explain why the development of all scientific knowledge does not require experimentation. Nancy, in contrary to her previous conceptions regarding the empirical NOS aspect, underscored the importance of observational evidence in life sciences at the end of her NOS teaching.

As for the inferential NOS, Nancy’s post-NOS training conceptions were very similar to her post-NOS training conceptions. She continued to provide very basic explanation for how scientists determined the structure of an atom. She believed that scientists used information obtained from technology together with prior knowledge to make sure about the structure of an atom. The following excerpt illustrates what Nancy thought how scientists determined the structure of the atom.

Nancy: I think they [scientists] used some pretty high powered microscopes to figure out [the structure of an atom]. I don’t know 100 % sure that they have actually been able to get that close, but I think that they probably got close enough that they could figure out how it worked.
The researcher: Do you think scientists do something else other than just using the technology to draw the model of an atom?

Nancy: I would think that they probably using the knowledge that they have about…They can’t get that close, but using the information that they have and what they already know they probably can [figure out the structure of an atom] [post-NOS teaching interview].

After teaching NOS, Nancy still could not explain how scientists used their observations and prior knowledge to make an inference about the structure of an atom.

Since the beginning of the professional development program, Nancy endorsed the tentative NOS aspect in general. She continued to think at the end of her NOS teaching that scientific knowledge could change with the availability of new information or technology. Unlike her pre-NOS conceptions, Nancy mentioned Galileo’s use of telescope as an example of how new technology could contribute to the changes and revisions in the scientific knowledge. Even though Nancy realized after the NOS training that scientific knowledge could also change with the availability of a new perspective on the existing data, she understood it better after teaching NOS.

Especially that last idea that somebody could look at the same set of data as somebody else did before and come up with a completely different outcome, I think, I could have probably thought about it before, but I would not have really conceptualized it well [post-NOS teaching interview].

The change Nancy expressed above seemed to be supported by her connections among tentative, subjective, and sociocultural NOS aspects. She believed that scientists’
personal subjectivity because of their past experiences could lead to changes in scientific knowledge. In addition, the culture and society in which science is practiced could influence scientists’ perceptions, and therefore, could contribute to change in scientific knowledge.

At the beginning of the training Nancy acknowledged the creative NOS in general, but she considered data collection as being more procedural than creative. After both post-NOS training and teaching, she was able to appreciate the role of creativity even during the data collection.

They [scientists] have to do it obviously to come up with the experiments in the first place to design them and then they have to during it if there’s anything going wrong or, you know, something is not working out right. Then they’re going to have to make some changes and figure out how they’re going to make those changes – what they’re going to change, and then after [data collection], they have to be able to look at it and say “well, why did this happen?” You know, it’s not just like cut and dry necessarily, like they’re going to record the results, but they’re also going to have to analyze what’s happened and really have to use your imagination and creativity in that piece because if you don’t then you’re not going to figure it out [post-NOS teaching interview].

In addition to the acknowledgement of the creativity as an integral part of scientific investigations, Nancy could also provide examples of how her students demonstrated their creativity and imagination during the Bottle activity and when she read the
children’s book *Seven Blind Mice* (Young, 1992). She drew a parallel between scientists’ creativity and the creativity demonstrated by her students during her NOS teaching.

When we were doing the *Seven Blind Mice*, they had to think about what that could be, like they had to imagine themselves being blind and coming up upon that particular piece and thinking what that would be. That’s totally a creative process because you have to imagine it in your mind. It’s not something you can do anything else with, so…I really enjoyed watching them in the *Bottle* activity because for me, it was interesting to see what they came up with and what they were able to, you know, um, imagine what it could be [Post-NOS teaching interview].

As seen in the above excerpt, Nancy explained that her students used their imagination and creativity to come up with what could be the thing the mice touched or what could be inside the bottle to hold it in the air, respectively. In other words, she continued to support her creative NOS conceptions with appropriate examples.

Nancy acknowledged the subjectivity in science since the beginning of this study. She continued to think after her NOS teaching that scientists could reach at different conclusions by looking at the same data set because of their prior knowledge and experience. Nancy also mentioned the role of communication among scientists as factor related to scientists’ subjectivity at the end of her NOS teaching. However, it should be noted that Nancy was able to better articulate her social NOS conceptions after NOS teaching compared to pre-NOS training. Furthermore, she started to underscore culture and society as an important factor related to scientists’ subjectivity after NOS teaching.
The following excerpt indicates Nancy’s post-NOS teaching conceptions regarding the subjective NOS aspect.

Nancy: People bring in a different set of background knowledge and information to the table, and so, they aren’t necessarily going to see the same set of data in the same way, and obviously those are all opinions about what state the universe is. So, I mean everybody has a different set of knowledge and they’re not always going to be the same as somebody else.

The researcher: Okay. Is there anything else other than different set of knowledge that might cause scientist to have different ideas?

Nancy: could also have to do with the culture in which you are practicing, too. I mean, that definitely has an influence on people’s opinions, too; like talking with other scientists, you know, being influenced by other scientists in the field [post-NOS teaching interview].

The aforementioned excerpt reveals that after teaching NOS Nancy listed not only personal factors, but also sociocultural and social factors to explain the subjectivity in science. However, she once again failed to elaborate on how these factors could lead scientists to reach at different conclusions from the same data set and to point out theoretical subjectivity in science.

Overall, I realized that Nancy’s post-NOS teaching conceptions were very similar to her post-NOS training conceptions. Supportively, when I asked Nancy during the interview what was responsible for the change, if any, in her NOS conceptions, she generally referred to the NOS training or her science teaching. It seemed that teaching
NOS did not make a big shift in Nancy’s NOS conceptions. Rather, it made her NOS conceptions more fruitful. For instance, for the creative NOS she stated “I knew that science had to be a creative process, but I just think that teaching it really made me see it more like in action” [post-NOS teaching interview].

**Andy’s Post-NOS Teaching Conceptions**

At the time of the study, Andy was responsible for teaching science in two fifth-grade classrooms. Students in both of his classrooms were high achievers at the school. Andy started his NOS teaching by introducing the NOS aspects to his high achieving students. To do this, he decided to use only Anna’s PowerPoint presentation rather than her worksheet because he thought that having his high achieving students also complete the worksheet after having watched videos would be boring and redundant. After this introductory NOS lesson, Andy used the *Bottle* activity to get his students’ attention. Then, he continued by reading *Seven Blind Mice* (Young, 1992) and doing the *Fossils* activity (Lederman & Abd-El-Khalick, 1998). Andy completed his NOS teaching by doing the *Tangram* activity (Choi, 2004) and the *Cube* activity (Lederman & Abd-El-Khalick, 1998). He purposefully did the *Tangram* and *Cube* activities at the end of his NOS teaching because he thought his high achieving students would be challenged to complete these two activities and they would work together.

At the end of his NOS teaching, Andy continued to appreciate that scientific knowledge is based on empirical evidence. He expressed during his interview that his empirical NOS conceptions were solidified after teaching NOS because it provided more concrete examples indicating the importance of evidence in scientific knowledge. For instance, in the *Bottle* activity, Andy stated that his students came up with different ideas
about what could be inside the bottle. One of his students claimed that there was a hand inside the bottle holding the string. He seized this opportunity to explicitly talk about the empirical NOS aspect by stating that this claim could not be scientific because one could not collect any evidence to test it. The following excerpt describes the influence of the NOS teaching on Andy’s empirical NOS conceptions.

Just thinking back, I think that this [the difference between scientific knowledge and opinion] is one of those things, I think, in my mind was pretty clear, but it is nice to have those more concrete examples for them to say, oh, I think it is a hand, that is grabbing the string in the bottle, and then it is easier than to say, oh, well, you know, what evidence do you have for that? You know, like what could you see if that’s to be true? And I think that it just gives an easier way for, as a teacher, to get them to understand, okay, if you’re going to make a theory or make a prediction of what’s going on, there has to be something supporting that. Then it is just a guess. It is a random shot in the dark [post-NOS teaching interview].

In addition to the necessity of empirical evidence in science, Andy also continued to solidify his conception about the role of empirical evidence in science after his NOS teaching. He once again highlighted that scientists use empirical evidence to justify their ideas or theories rather than prove or disprove them: “The results of the experiment are not like it’s done. We’ve proved it. It’s just saying, we’re finding more results that are consistent with what we believe or if it’s not, now it’s time to start changing what we think” [post-NOS teaching interview]. Andy also clarified further his NOS conception that empirical evidence could be both observational and experimental. For instance, he
elaborated during his post-NOS teaching interview that geologists have to base their understanding of geological phenomena based on their observations because one’s life span would not be enough to conduct experiments about geological processes that might take millions of years.

When I asked Andy to comment on the question about what an atom looks like, he took this occasion to talk about the tentative NOS aspect (the revisions of the atom models in the history of science). However, Andy expressed his inferential NOS conceptions with the atom question at the beginning of the study (scientists’ inferences about the structure of an atom based on their observations).

After NOS teaching, Andy again thought that scientific knowledge could change with the availability of not only new information or technology but also a new perspective on the existing data as seen in the following excerpt.

Again I would say it [scientific knowledge] changes because of a couple different things. One, it could just be that some new information or new technology becomes available, where now we can know more than we did before, have more access to observations that we had no ability to make before. So, you have that. And also there may be someone who, you know, just reconsiders something that was already there and maybe can gleam some sort of pattern that was previously there, but wasn’t noticed until now, you know. So, I would say it’s one of those two things [post-NOS teaching interview].

At the end of his NOS teaching, Andy also continued to explain his tentative NOS conceptions with several examples from history of science and NOS training activities.
For instance, Andy drew a parallel between how scientists revised their ideas and how his students revised their ideas during the Bottle activity with the availability of new information. Although Andy held very similar tentative NOS conceptions at the end of his NOS teaching, he started to conceptualize the tentative NOS aspect from a more holistic perspective. During the post-NOS teaching interview, he expressed that teaching the tentative NOS through the NOS activities helped his students to view science as a human endeavor as illustrated in the following excerpt.

When you just hear a summary of it, like they did this and then they did this and then they did this, I think it kind of seems very dry and like oh, this was obvious and this is the next step and the next step and the next step like, well, you know, of course they’re going to figure that out, but when they have that experience, I think it makes it a lot more humanizing for them that they can see like this was an idea that someone maybe spent a long time on, and it makes them see that this is not, you know, more of like science is just this robotic thing that’s happening and oh, well, eventually someone is going to figure that out and no, don’t worry about it. We’ll get it eventually and it’s obvious that this is the next discovery that will be made, but it’s not, you know. Each little step is a major discovery that someone is going to be very excited or very devastated about it being changed or that they have to revise their theory [post-NOS teaching interview].

After teaching NOS, Andy continued to think that scientists use their creativity and imagination at every step of their work, especially in data analysis. Although he did not change so much his creative NOS conceptions, Andy realized that teaching creative
NOS could help his students to appreciate the human side of science because he observed that most of his students considered scientists as robots performing routine tasks such as mixing chemicals in the laboratories rather than using their creativity and imagination in doing their work. The following excerpt illustrates Andy’s conceptions of creative NOS after his NOS teaching.

I would say that this whole experience really, again not that I didn’t think that you had to have creativity before, but I think it just made way more obvious how much science is done in your mind. It is done in the envisioning of solutions, the envisioning of a pattern, you know, analysis of all that stuff. If you make an experiment, the experiment usually is a very small amount of what you are doing.

I think that with kids again, they think if you are a scientist, you are in a laboratory all day and you are mixing chemicals all day and all this stuff. I think that they would be like very surprised to find out that the people who do that all day are people that really are not scientists [but technicians] and not being paid a lot of money whereas the scientists is the person who is sitting and really taking this information and putting it into their brain and trying to come up with what’s going on. I think that it is a similar to an artist who is actually crafting, but it is really again in their mind [post-NOS teaching interview].

Similar to his creative NOS conceptions, Andy expressed that teaching NOS helped him to solidify his subjective NOS conceptions. He interpreted what his students did during NOS activities from the perspective of subjective NOS aspect. He mentioned that his students had variety of ideas explaining the same phenomenon during NOS
activities, and that they defended their ideas until there is overwhelming evidence discrediting their ideas. In addition, he started to explain the subjectivity in science from a more holistic perspective of science as a human endeavor. After his NOS teaching, Andy started to think that science is inherently subjective because it is done by people who are themselves subjective as seen in the following excerpts.

It was good for the kids to see, like I said, some of the things we did in class and then that it’s humans doing this. There’s going to be mistakes. There’s going to people who get upset. People have a rivalry and they don’t want their friend or their enemy to get credit for something [post-NOS teaching interview].

I think that we watched some of these videos, too, where it started to make it a lot more, again, human for them to see that this is people’s thoughts and that they get attached to them or that they see a rival scientist coming up with something that’s maybe disproving their theory, and so, they want to discredit that person. I don’t think they [students] saw science as competitive or human endeavor [post-NOS teaching interview].

As for the bounded NOS, Andy also seemed to clarify his NOS conceptions after his NOS teaching. He underscored during his post-NOS interview that it was easier for him to explain someone the reason why he talked about the Big Bang theory (scientific understanding about the origin of the universe) rather than God’s creation of the universe (religious understanding about the origin of the universe) in his science classrooms. After the NOS teaching experience, he also continued to differentiate scientific versus nonscientific understanding of a situation by appealing to empirical evidence. The
following excerpt indicates the overall influence of NOS teaching experience on Andy’s NOS conceptions regarding the limits of science.

I don’t think that it was a drastic change, but I think it just clarified and solidified… I would say they [science and religion] are two different things. If you want to have a religious belief about it, great, but this is the science, you know. So, it’s not like just however you feel. This is what evidence is there for? What documentation do you have for? [post-NOS teaching interview].

In summary, I realized that teaching NOS provided Andy an opportunity to test the validity of his informed NOS conceptions with his students. Therefore, the NOS teaching experience helped Andy to further solidify his NOS conceptions. Given that Andy already held very sophisticated NOS conceptions at the end of the NOS training, it should not be surprising not to find any dramatic changes in his NOS conceptions at the end of his NOS teaching. However, it is noteworthy that the NOS teaching experience helped Andy to develop some ideas about how to teach NOS more effectively rather than to enhance his NOS understanding as seen in the following excerpt.

I think it just helped me to come up with better ways to explain it [NOS] to kids, like for instance something we are doing in math. When I first started teaching the math, I may have understood it, but I did not know the best way to get a kid to understand it. I did not know the best way to phrase it to say… So, this [NOS teaching experience] kind of helped me to come up with easier ways. Let’s say we could’ve got the same thing done over the course of fifteen minutes. Now, I
would say, I can maybe explain that to them in five minutes, you know. It just made it more efficient [post-NOS teaching interview].

**Cross-case Analysis of Post-NOS Teaching NOS Conceptions**

The cross-case analysis revealed that the NOS teaching helped the participants to further elaborate their NOS conceptions. I realized that they developed additional connections among the NOS aspects. For example, in addition to her connection between creative and inferential NOS aspects at end of the NOS training Francine also linked the creative NOS aspect with the subjective NOS aspect at the end of the NOS teaching. Similarly, other participants also made new connections among NOS aspects after teaching NOS. I also realized that the participants elaborated their NOS conceptions by using more examples with increased amount of detail. For example, at the beginning of the NOS teaching Anna gave a very brief surface level explanation about her inferential NOS conceptions, but her inferential NOS explanations were more lengthy and sophisticated after teaching NOS. Anna explained her inferential NOS conceptions by providing examples from two NOS activities that she taught in her classrooms.

The NOS teaching also helped the participants to further increase their confidence in their NOS conceptions. I think that participants’ increased knowledge about NOS helped them to feel more confident in their NOS conceptions. They all repeatedly expressed how confident they felt in their NOS conceptions after teaching NOS because they saw that their NOS knowledge and NOS activities proved to be fruitful in actual classroom settings.

I also realized that after the NOS teaching experience three of the four participants continued to acknowledge the role of both experimental and observational
evidence in science similar to their post-NOS training conceptions. Francine reverted back to her original conceptions regarding the definition of experiment. Therefore, at the end of her NOS teaching, she once again considered experimentation as a main route to collecting empirical evidence. In other words, the NOS teaching experience did not help Francine to solidify her post-NOS training conception that science is based on both experimental and observational evidence.

**Research Question Two**

The second research question of this study was concerning the changes in the participating elementary teachers’ beliefs about the appropriateness and importance of teaching the nine NOS aspects after participating in a one-year professional development program. For the aforementioned purpose, the participants’ beliefs of developmental appropriateness and importance were examined at three occasions: at the beginning of the professional development, after their participation in the NOS training, and after teaching several NOS lessons in their classrooms. Accordingly, the findings related to the second research question are presented in three sections: pre-NOS training beliefs, post-NOS training beliefs, and post-NOS teaching beliefs. After presenting the findings of individual case analysis, cross-case analysis is provided in order to show similarities and differences in the participants’ NOS beliefs at the beginning of the professional development program, after participating in the NOS training, and after teaching several NOS lessons in their own classrooms. The following figure illustrates a general overview of the presentation of the findings regarding the second research question.
Figure 4. The overview of the presentation of the second research question findings.

Pre-NOS Training Beliefs

This section consists of two sub-sections. First, it presents the findings obtained from the analysis of each participant’s pre-NOS training beliefs about the developmental appropriateness and importance of teaching the nine NOS aspects. Second, it presents the findings obtained from the cross-case analysis of the participants’ pre-NOS training beliefs about the developmental appropriateness and importance of teaching the nine NOS aspects at their grade level.

Francine’s Pre-NOS Training Beliefs

At the beginning of the professional development program, Francine did not find any of the NOS ideas inappropriate/unimportant to teach at the third grade level because she did not assign 1 (not at all appropriate/not at all important) to any of the NOS ideas and she indicated that she planned to teach all of these NOS ideas during the academic year. The Table 1 presents Francine’s pre-ratings for the developmental appropriateness
and importance of each idea about science individually (individual ratings), her pre-ratings for the developmental appropriateness and importance of each idea about science compared to other ideas (relative ratings), and her description of the action for teaching each of these nine ideas about science.

Table 1
Francine’s Pre-NOS Training Ratings for the Developmental Appropriateness and Importance of Teaching Ideas about Science for her Third Graders

<table>
<thead>
<tr>
<th>Idea about science</th>
<th>Appropriateness</th>
<th>Importance</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Individual</td>
<td>Relative</td>
</tr>
<tr>
<td>Inferential NOS</td>
<td>5</td>
<td>6(^d)</td>
</tr>
<tr>
<td>Creative NOS</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Tentative NOS</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Empirical NOS</td>
<td>5</td>
<td>1(^d)</td>
</tr>
<tr>
<td>Subjective NOS</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Socio-cultural NOS</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Scientific Methods</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Collaborative NOS</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Bounded NOS</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

Note. \(^a\)For the individual ratings, the participant showed his or her degree of agreement regarding each idea about science from 1 (not at all appropriate or important) to 5 (very appropriate or important). \(^b\)For the relative ratings, the participant ranked the nine ideas about science from 1 representing “the most appropriate or important idea about science” to 9 representing “the least appropriate or important idea about science”. \(^c\)The participant described her action or plan for teaching the NOS aspects by selecting “I already taught this idea in previous year(s)”, “I plan to teach this idea this school year”, or “I will not teach this idea this school year”. \(^d\)The participant switched her ratings for the empirical and inferential NOS aspects because she could not differentiate between the provided definitions of these two NOS aspects.

Among the nine ideas about science, Francine considered only the idea that science cannot answer questions related to philosophy, religion, or ethics “neither appropriate nor inappropriate” and “neither important nor unimportant” to teach at the third grade level (See Table 1). During her follow-up interview, she explained her low
ratings for the bounded NOS aspect with the abstractness of the terms such as philosophy, religion, and ethics. Even though Francine believed that it is not very appropriate and important to teach the bounded NOS aspect at the third grade level, she placed this NOS aspect above the creative, tentative, and subjective NOS aspects that she rated as “very appropriate” and “very important”. This inconsistency between her individual and relative ratings for the bounded NOS aspect seemed to imply that she did not rank the developmental appropriateness and importance of the nine ideas about science based on their abstractness.

In addition to the bounded NOS aspect, Francine seemed to have some concerns regarding the appropriateness of the idea that science is based on both observation and inference because during her follow-up interview she highlighted third grade students’ having poor inference skills: “They do observations every day in their life, but they really do not know how to shape those ideas to reach the end. They have lack of inference actually” [pre-NOS training beliefs interview]. Despite of her concern about third grade students’ ability to make inference, she believed that it is “very appropriate” to teach the inferential NOS aspect because teaching this idea would help her students in three ways. First, Francine believed that when she taught the inferential NOS aspects, her students might clear their misconception that “science is only fun and scientists do experiments only” [pre-NOS training beliefs interview]. Second, teaching the inferential NOS aspect could help her students to become good problem solvers. Third, knowing the difference between observation and inference would promote their science learning at upper grades as illustrated in the following excerpt.
If they don’t know the difference between this [observation and inference] and how to use it, I am not sure that they can be ready for the next grade level because in the fourth and fifth grade they have more expectations. They will be more individual learners. If we start training them at this third grade level, I think they will do a better part in fifth grade, [be] more successful and they are going to like science more, I think [pre-NOS training beliefs interview].

In other words, Francine’s beliefs about the importance of teaching the inferential NOS aspect seemed to diminish her concerns about the appropriateness of this NOS aspect.

Similar to the inferential NOS aspect, Francine explained the developmental appropriateness of teaching the idea that science is based on the observations of the natural world with her beliefs about the importance of teaching this idea to her students. During the follow-up interview, Francine expressed that an understanding of the empirical NOS aspect is a prerequisite to learning about the absence of the scientific method: “Everything starts with observation, I think. If they are good observers, I can teach them like the number 8 there is no single step by step scientific method” [pre-NOS training beliefs interview]. Therefore, she considered the empirical NOS aspect as the most appropriate/ important idea about science.

After the empirical NOS aspect, Francine ranked the idea about the absence of single scientific method as the most appropriate idea about science (See Table 1). She believed that it is very appropriate to teach about the myth of the scientific method because of its importance in students’ science learning: “I believe they can capture because this is how we start the year. At least three weeks we are spending about the scientific method… I think it is very important… This knowledge will help them grasp
different subjects in a better way” [pre-NOS training beliefs interview]. Aforementioned quotation also showed that Francine could not internalize the meaning of the absence of single scientific method because she pointed out the importance of teaching the so-called single scientific method.

In addition to the top ranked NOS aspects (empirical NOS aspect and the so-called scientific method), Francine was not able to differentiate between appropriateness and importance of the bottom ranked NOS aspects (tentative and creative NOS). She expressed during the follow-up interview that students should first learn the tentative NOS aspect in order to understand the creative NOS aspect. Therefore, she considered teaching the tentative NOS aspect more appropriate/important than teaching the creative NOS aspect.

In summary, at the beginning of the professional development program Francine did not differentiate between appropriateness and importance of teaching NOS aspects. She brought up different reasons why an idea about science is developmentally appropriate or important to teach at the third grade level. Therefore, Francine unconsciously provided inconsistent ratings for the developmental appropriateness and importance of some NOS aspects. These inconsistent ratings were sometimes also related to her misconceptions about those NOS aspects.

**Anna’s Pre-NOS Training Beliefs**

At the beginning of the professional development program, Anna overall believed in the developmental appropriateness and importance of teaching NOS by stating, “I think every single one of these concepts is important. I think in fifth grade they are developmentally appropriate. They are able to do every single one of these” [pre-NOS
training beliefs interview]. However, she raised some concerns about the developmental appropriateness and importance of certain NOS aspects when she started to individually talk about NOS aspects (See Table 2).

Table 2

\textit{Anna’s Pre-NOS Training Ratings for the Developmental Appropriateness and Importance of Teaching Ideas about Science for her Fifth Graders}

<table>
<thead>
<tr>
<th>Idea about science</th>
<th>Appropriateness</th>
<th>Importance</th>
<th>Teaching</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Individual(^a)</td>
<td>Relative(^b)</td>
<td>Individual(^a)</td>
</tr>
<tr>
<td>Inferential NOS</td>
<td>5</td>
<td>1</td>
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</tr>
<tr>
<td>Creative NOS</td>
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<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Tentative NOS</td>
<td>5</td>
<td>2</td>
<td>5</td>
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<tr>
<td>Empirical NOS</td>
<td>4</td>
<td>9</td>
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<tr>
<td>Subjective NOS</td>
<td>4</td>
<td>4</td>
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</tr>
<tr>
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<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Collaborative NOS</td>
<td>4</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Bounded NOS</td>
<td>4</td>
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\textit{Note.} \(^a\)For the individual ratings, the participant showed his or her degree of agreement regarding each idea about science from 1 (not at all appropriate or important) to 5 (very appropriate or important). \(^b\)For the relative ratings, the participant ranked the nine ideas about science from 1 representing “the most appropriate or important idea about science” to 9 representing “the least appropriate or important idea about science”. \(^c\)The participant described her action or plan for teaching the NOS aspects by selecting “I already taught this idea in previous year(s)”, “I plan to teach this idea this school year”, or “I will not teach this idea this school year”.

Among the nine ideas about science, Anna found five ideas about science (empirical, creative, subjective, collaborative, and bounded NOS aspects) “somewhat appropriate” as presented in Table 2. She considered the idea that science is based on the observations of the natural world as the least appropriate idea because she thought that fifth grade students should have mastered this idea about science at previous grades. Therefore, she indicated that she would just review the empirical NOS aspect at the fifth
grade level. This indicates that she assessed teaching empirical NOS aspect from the grade level appropriateness perspective rather than developmental appropriateness perspective. Anna’s assessment of the grade level appropriateness of teaching the empirical NOS at the fifth grade seemed to influence her beliefs about the importance of teaching the empirical NOS aspect.

As for the creative NOS aspect, Anna believed that her students could understand this aspect easily. She rated it as “somewhat appropriate” and placed it at the bottom of her list because she considered “students are naturally creative” and there is no need to spend more time on teaching the creative NOS aspect [pre-NOS training beliefs questionnaire].

Unlike the empirical and creative NOS aspects, Anna thought that the collaborative NOS aspect is not developmentally appropriate because understanding this particular NOS aspect is relatively difficult for fifth grade students: “I wrote somewhat appropriate because a lot of fifth graders have a hard time [to understand the idea of critical review]. When you tell critically review peers, they take it around with it. So, that is really got to be taught little by little” [pre-NOS training beliefs interview]. Anna believed that it is very important to teach the collaborative NOS aspect at the fifth grade, but fifth grade students might not understand this idea about science quickly because of their lack of ability to critically review the work of peers at this age.

Similar to the collaborative NOS aspect, Anna raised concerns about the developmental appropriateness of the subjective and bounded NOS aspects, but she also questioned the importance of teaching these two NOS aspects. Anna believed that it is “somewhat appropriate” and “slightly important” to teach the subjective NOS aspect
because “students might take this concept to extreme” [pre-NOS training beliefs questionnaire]. As for the bounded NOS, she thought that it is “somewhat appropriate” and “somewhat important” to teach at the fifth grade. Anna’s concerns about both the developmental appropriateness and importance of teaching the subjective and bounded NOS aspects seemed to have a deep impact on her action for teaching them in her classroom because only for these two NOS aspects Anna reported on her questionnaire that she was “unsure” (See Table 2 for detailed information about her actions across NOS aspects). In this regard, it is questionable why she did not place the subjective and bounded NOS aspects at the bottom of her list when she compared the developmental appropriateness and importance of teaching the nine ideas about science.

Among the nine ideas about science, Anna didn’t have any doubt about the developmental appropriateness and importance of teaching the following three ideas about science: (a) science is based on both observation and inference, (b) scientific knowledge is tentative, and (c) there is not a single step by step “scientific method” by which all science is done. She believed that each of these three ideas about science is “very appropriate” and “very important” to teach at the fifth grade (See Table 2), and consistently, she placed these three ideas about science at the top of her lists when she compared the developmental appropriateness and importance of the nine ideas about science. During her follow-up interview, Anna explained why she considered the inferential NOS aspect as the most appropriate/important idea about science by stating “inference is a relatively new concept in fifth grade and target for them, but stuff like observation we don’t need to focus on as much because they had been doing it since they
were in kindergarten” [pre-NOS training beliefs interview] and “students are focusing on inferencing in many other areas in this grade” [pre-NOS training beliefs questionnaire].

Overall, I realized that Anna’s assessment of the developmental appropriateness of teaching an idea about science was closely related to her beliefs about the importance of teaching that idea. Moreover, her description of the action for teaching an idea about science seemed to be consistent with her beliefs about the developmental appropriateness and importance of teaching that idea. It is interesting to note that Anna did not mark “I already taught this idea in previous year(s)” option about her teaching when she has doubts about developmental appropriateness and/or importance of any NOS aspect. Finally, Anna sometimes provided inconsistent ratings when assessing the developmental appropriateness and importance of the NOS aspects because the concepts of developmental appropriateness and importance were not mutually exclusive in her mind. Moreover, Anna’s interpretation of NOS aspects were not always aligned with provided NOS definitions. Often times, she rated or ranked the NOS aspects in terms of developmental appropriateness and importance by adhering to her own peculiar definitions rather than the given NOS definitions.

**Nancy’s Pre-NOS Training Beliefs**

At the beginning of the NOS training, as seen in Table 3, Nancy did not consider any of the NOS ideas as inappropriate or unimportant to teach, but she was not sure whether these ideas are actually appropriate or important to teach at the fifth grade. During the follow-up interview, Nancy explained her lack of confidence in her beliefs about the developmental appropriateness and importance of teaching the ideas about science with her lack of teaching experience in science: “I am not sure, honestly. I mean I
think that they are all important and appropriate. Having not taught science, it is really
difficult for me to truly rate these appropriately” [pre-NOS training beliefs interview].

Table 3

*Nancy’s Pre-NOS Training Ratings for the Developmental Appropriateness and
Importance of Teaching Ideas about Science for her Fifth Graders*

<table>
<thead>
<tr>
<th>Idea about science</th>
<th>Appropriateness</th>
<th>Importance</th>
<th>Teaching</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Individual(^a)</td>
<td>Relative(^b)</td>
<td>Individual(^a)</td>
</tr>
<tr>
<td>Inferential NOS</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Creative NOS</td>
<td>5</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Tentative NOS</td>
<td>5(^d)</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Empirical NOS</td>
<td>5</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Subjective NOS</td>
<td>5(^d)</td>
<td>5</td>
<td>5(^d)</td>
</tr>
<tr>
<td>Socio-cultural NOS</td>
<td>5</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Scientific Methods</td>
<td>5</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Collaborative NOS</td>
<td>5(^d)</td>
<td>9</td>
<td>5(^d)</td>
</tr>
<tr>
<td>Bounded NOS</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

*Note.* \(^a\)For the individual ratings, the participant showed his or her degree of agreement regarding each idea about science from 1 (not at all appropriate or important) to 5 (very appropriate or important). \(^b\)For the relative ratings, the participant ranked the nine ideas about science from 1 representing “the most appropriate or important idea about science” to 9 representing “the least appropriate or important idea about science”. \(^c\)The participant described her action or plan for teaching the NOS aspects by selecting “I already taught this idea in previous year(s)”, “I plan to teach this idea this school year”, or “I will not teach this idea this school year”. \(^d\)The participant changed her questionnaire rating from 4 to 5 during the interview.

At the beginning of the NOS training, Nancy found only two ideas about science (the inferential and bounded NOS aspects) as “somewhat appropriate” to teach at the fifth grade. As for the inferential NOS aspect, she explained why she believed it is not very appropriate to teach as follows: “I don’t think it is difficult for them to understand it. The reason I said that is because I don’t think that all of the instruction that we give at the fifth grade is going to be based on experiments” [pre-NOS training beliefs interview].
Nancy thought that teaching the inferential NOS aspect is depended on doing experiments in the classroom. This indicates that Nancy misinterpreted the given definition for the inferential NOS aspect.

Unlike the inferential NOS aspect, Nancy seemed to have real a concern about the developmental appropriateness of teaching the bounded NOS aspect at the fifth grade. During the follow-up interview, she expressed that it is somewhat difficult to teach the idea that science cannot answer questions related to art, philosophy, religion or ethics because “kids at this age they know about art and religion to a certain extent, but ethics and philosophy are pretty far reaching for a lot of the knowledge base for fifth graders” [pre-NOS training beliefs interview]. Moreover, Nancy had some doubts about whether the idea about the limits of science is an important part of her curriculum. Therefore, she noted “not sure” on her questionnaire to describe her action or plan for teaching the bounded NOS aspect. In other words, Nancy seemed to use not only her beliefs about the difficulty level of teaching the bounded NOS aspect but also her perception of the science content in her curriculum as a basis for her decision making about the inclusion of the bounded NOS aspect in her science teaching.

When Nancy’s reasoning for her ratings about the developmental appropriateness of the nine NOS aspects was taken into account, she seemed to question only the developmental appropriateness of teaching the bounded NOS aspect at the fifth grade. However, Nancy placed the collaborative NOS aspect instead of the bounded NOS aspect at the bottom of her list when she ranked the developmental appropriateness of the nine NOS aspects. During the follow-up interview, Nancy explained this inconsistency between her individual and relative ratings about the developmental appropriateness of
teaching the collaborative NOS aspect with her beliefs about the importance of teaching the collaborative NOS aspect as seen in the following excerpt.

I don’t think it is difficult for them to grasp it. I was talking about more importance of like that would not, to me, be one of the main things. If I had a list of things that I had to teach them and only a certain time to do them, that would not be high on my list [pre-NOS training beliefs interview].

In other words, Nancy did not consider the collaborative NOS aspect as important as the other NOS aspects. In this regard, her perception of the science content in her curriculum once again seemed to influence her rating because Nancy noted on her questionnaire that she was “not sure” whether the collaborative NOS aspect was one of the core concepts that were expected to be taught at the fifth grade (See Table 3 for Nancy’s description of her actions or plans for teaching each idea about science).

In addition to the bottom NOS aspects (collaborative, creative, and tentative NOS aspects), Nancy rated the developmental appropriateness of the top NOS aspects based on their relative importance in science. Accordingly, she considered the idea about the absence of the scientific method, inferential NOS aspect, and empirical NOS aspects as the most appropriate ideas about science to teach at the fifth grade because “they are probably part of the core concepts that are expected to be taught” [pre-NOS training beliefs interview].

In summary, Nancy determined to what extent a particular NOS aspect was developmentally appropriate based on the extent to which she perceived this particular NOS aspect had an important place in science and/or science curriculum. I think this
seem to be related to her lack of science teaching experience in general and her lack of
teaching experience at the fifth grade level in particular.

**Andy’s Pre-NOS Training Beliefs**

At the beginning of the professional development program, Andy did not rate any
of the nine ideas about science as inappropriate or unimportant to teach at the fifth grade.
However, he believed that some NOS aspects are more appropriate or important to teach
than other NOS aspects. See Table 4 for Andy’s ratings for the developmental
appropriateness and importance of teaching each idea about science.

<table>
<thead>
<tr>
<th>Idea about science</th>
<th>Appropriateness</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Individual(^a)</td>
<td>Relative(^b)</td>
</tr>
<tr>
<td>Inferential NOS</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Creative NOS</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Tentative NOS</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Empirical NOS</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Subjective NOS</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Socio-cultural NOS</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Scientific Methods</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Collaborative NOS</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Bounded NOS</td>
<td>3</td>
<td>8</td>
</tr>
</tbody>
</table>

Note. \(^a\)For the individual ratings, the participant showed his or her degree of agreement
regarding each idea about science from 1 (not at all appropriate or important) to 5 (very
appropriate or important). \(^b\)For the relative ratings, the participant ranked the nine ideas
about science from 1 representing “the most appropriate or important idea about science”
to 9 representing “the least appropriate or important idea about science”. \(^c\)The participant
described his action or plan for teaching the NOS aspects by selecting “I already taught
this idea in previous year(s)”, “I plan to teach this idea this school year”, or “I will not
Teach this idea this school year”.

196
Among the nine ideas about science, Andy raised doubts about the developmental appropriateness of the bounded and subjective NOS aspects because he rated only these two ideas about science as “neither appropriate nor inappropriate”; he placed these two ideas at the bottom of his list; and he did not teach only these two ideas about science in previous years (See Table 4). During the follow-up interview, Andy explained that he put both the bounded and subjective NOS aspects into the same category because an understanding of these ideas about science requires higher-level thinking such as acknowledgement of the existence of multiple truths or perspectives. The following excerpt points out Andy’s beliefs about the developmental appropriateness of teaching the bounded NOS aspect at the fifth grade.

I think there is a couple in here that sort of I would say fall into that category, like science cannot answer all questions. I think that’s another one that’s a higher level of thinking. That really requires you to know more of yourself before you can start applying that, you know, again sort of falls into that like is there one answer or not? The answer should be science can’t explain everything…To accept that there are questions that cannot be answered, that’s a more philosophical thing, I think [pre-NOS training beliefs interview].

The above excerpt indicates that the bounded NOS aspect was not the only idea about science that Andy believed not very appropriate for fifth grade students.

One might think that Andy also questioned the developmental appropriateness of the creative and collaborative NOS aspects because he rated the creative NOS aspect as “somewhat appropriate” while he placed the collaborative NOS aspect at the bottom of
his list while comparing the developmental appropriateness of the nine ideas about science. However, Andy’s reasoning for the ratings of these two NOS aspects wasn’t related to whether fifth grade students could grasp these ideas about science or not. For instance, Andy stated on his questionnaire that it is somewhat appropriate to teach the idea that science is a creative process because “children are naturally curious to make sense of things”. In other words, Andy assessed the developmental appropriateness of the creative NOS aspect based on his beliefs about the importance of teaching this idea about science.

As for the inferential NOS aspect, Andy rated the idea that science is based on observation and inference as “somewhat appropriate” (See Table 4) because he thought that “there is not always time to ‘discover’ everything, some things you just have to read and accept as true” [pre-NOS training beliefs interview]. Here, Andy did not focus on students’ philosophical understanding of science. Rather, he talked about teaching science through discovery. Unlike his individual rating, Andy ranked the inferential NOS aspect as the most appropriate idea about science. During the follow-up interview, Andy explained why he considered teaching the inferential NOS aspect more appropriate than teaching the subjective NOS as follows.

Some of them [NOS aspects] I think are very totally appropriate and easy for children to understand. I mean, I think like science is based on observation and inference, you know, that’s pretty much something that it’s an easier concept for kids to get. You observe things and then make a conclusion about what you see. Some of them are a little bit harder for them to get to like, for example, scientific knowledge is not entirely objective. Personal values and all that stuff will go into
it. I think that is very like a higher level idea that especially as the standards are written currently is not required for them to know to do their best on the exams [pre-NOS training beliefs interview].

As seen in the above excerpt, Andy actually believed that teaching the inferential NOS aspect is “very appropriate” rather than “somewhat appropriate” at the fifth grade. He thought that fifth graders could easily grasp the inferential NOS aspect because they do not need higher-order thinking as opposed to an understanding of the subjective NOS. In addition to its developmental appropriateness, Andy considered the inferential NOS aspect as “very important” to teach at the fifth grade because he believed that “it is the basis of all scientific knowledge” [pre-NOS training beliefs questionnaire].

Unlike the inferential NOS aspect, Andy considered the bounded NOS aspect as the least important idea about science because he perceived that “it is not completely necessary for the standards” [pre-NOS training beliefs questionnaire]. In other words, Andy thought that he is not expected to teach the bounded NOS aspect at the fifth grade because it is not included in the science standards. Not surprisingly, the bounded NOS aspect was one of the two ideas about science that Andy did not teach in previous years. In addition to the content of the science standards, Andy also assessed the importance of teaching ideas about science based on her beliefs about the developmental appropriateness of these ideas about science. The following excerpt presents Andy’s reasons why he considered teaching the subjective NOS aspect less important than other NOS aspects.
I think it is very difficult for all but, you know, most bright and intuitive children to get in the first place, and second, being that it is not necessarily required to understand the things that they need to know to, you know, be proficient for fifth grade, those two things put together, I would say, we’re not going to spend a lot of time on this. Even if you can sort of talk about it, it is not worth like digging into [pre-NOS training beliefs interview].

In summary, there were birectional relationship between Andy’s beliefs about the developmental appropriateness and importance of teaching NOS aspects. Moreover, his beliefs were influenced by his perception of the inclusion of the NOS aspects in the standards or examinations. Finally, Andy’s beliefs about the developmental appropriateness and importance of teaching NOS aspects seemed to guide his actions for teaching them in his classroom.

Cross Case Analysis of Pre-NOS Training Beliefs

The cross-case analysis revealed some similarities and differences in the participants’ beliefs about the developmental appropriateness and importance of teaching the nine ideas about science which are presented in the following paragraphs.

One of the observed similarities was that participants’ beliefs about the developmental appropriateness of teaching NOS were not totally independent from their beliefs about the importance of teaching NOS. This relationship between the developmental appropriateness and importance of NOS appeared in the participants’ both individual and relative ratings. For instance, Francine copied her order for the developmental appropriateness of the nine ideas about science when she ranked the importance of teaching these nine ideas about science (See Table 5). Moreover, she rated
teaching the idea that science cannot answer questions related to art, philosophy, religion, or ethics as “neither important nor unimportant” because she believed that third graders are not developmentally ready to learn about abstract terms such as philosophy and religion, but they could understand science cannot answer all questions.

Second, all of the participants believed in the developmental appropriateness and importance of teaching NOS in general. They all thought that their students could grasp each of the nine ideas about science to a certain extent and they could get some value from being taught about these ideas about science because they did not rate any of the NOS aspects as inappropriate or unimportant to teach at their grade level (See Table 5).

Third, all of our participants believed that although students could grasp the nine ideas about science, they don’t learn them at the same rate. Regardless of their grade level, the participating elementary teachers agreed on that students need more time to understand the ideas that science cannot answer questions related to art, philosophy, religion, or ethics and that science is not entirely objective. Moreover, they all believed that their students could easily understand the ideas that there is not a single step-by-step “scientific method” by which all science is done and that science is based on observations of the natural world.

Fourth, all of our participants believed that although all of the ideas about science are important to teach, some of them are more beneficial for their students to learn. Regardless of their grade level, the participating elementary teachers agreed on that their students should learn the idea that there is not a single step-by-step “scientific method” by which all science is done because such an understanding would help them to do the science fair projects in a better way. They also thought that it is not very important to
teach the idea that science cannot answer questions related to art, philosophy, religion, or ethics because such an understanding about the limits of science is not very appropriate to teach (another evidence for the aforementioned relationship between beliefs about developmental appropriateness and importance of teaching the NOS aspects).

Fifth, the participating teachers did not assess the developmental appropriateness and importance of the NOS aspects based on only their thoughts about whether students could grasp the idea or they could get benefits from learning the idea. They sometimes determined the developmental appropriateness and importance of the NOS aspects based on their years of science teaching, their knowledge/perception about the content of science standards, curriculum or examinations, their distorted NOS conceptions, and/or their grade level. For instance, as a first year science teacher Nancy raised doubts about the developmental appropriateness and importance of the collaborative and bounded NOS aspects because she was not sure whether these two NOS aspects were included in her textbook or curriculum. On the other hand, Andy who was an experienced science teacher questioned the developmental appropriateness and importance of the subjective and bounded NOS aspects because he knew that these NOS aspects were not present in the science standards or examinations. As for the influence of NOS knowledge on the teacher beliefs, Francine was a case in point because she talked about how she actually taught “the scientific method” in her classrooms to support her beliefs about the importance of teaching the idea that there is not a single step-by-step “scientific method”. Teachers also show variations in their beliefs about the developmental appropriateness and importance of teaching certain NOS aspects based on their grade level: Our third
grade teacher, Francine considered the collaborative NOS aspect among the most appropriate/important ideas about science in contrary to our fifth grade teachers.

Finally, I observed that teachers’ beliefs about the developmental appropriateness/importance of NOS affect their actions for teaching NOS, but the degree of this impact might vary across teachers. For instance, Anna and Andy did not find any of the NOS aspects inappropriate or unimportant to teach at the fifth grade, but they both had some doubts about the developmental appropriateness/importance of teaching the subjective and bounded NOS aspects (See Table 5). Despite of these similarities in their beliefs about the developmental appropriateness/importance of teaching the NOS aspects, Anna stated that she was not sure about her actions for teaching the subjective and bounded NOS aspects in her classroom. Andy, on the other hand, reported that he taught all NOS aspects, except the subjective and bounded NOS aspects in previous years, but he plans to teach these two NOS aspects in the school year.
Table 5
The Participants’ Pre-NOS Training Ratings for the Developmental Appropriateness and Importance of Teaching the Ideas about Science

<table>
<thead>
<tr>
<th>Idea about science</th>
<th>Francine</th>
<th>Anna</th>
<th>Nancy</th>
<th>Andy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>App</td>
<td>Imp</td>
<td>Teaching</td>
<td>App</td>
</tr>
<tr>
<td>Creative</td>
<td>5/B</td>
<td>5/B</td>
<td>Plan to teach</td>
<td>4/B</td>
</tr>
<tr>
<td>Subjective</td>
<td>5/B</td>
<td>5/B</td>
<td>Plan to teach</td>
<td>4/M</td>
</tr>
<tr>
<td>Socio-cultural</td>
<td>5/M</td>
<td>5/M</td>
<td>Plan to teach</td>
<td>5/B</td>
</tr>
<tr>
<td>Collaborative</td>
<td>5/T</td>
<td>5/T</td>
<td>Plan to teach</td>
<td>4/M</td>
</tr>
</tbody>
</table>

Note. \( ^{a} \)“App” means the appropriateness of teaching the corresponding idea about science. \( ^{b} \)“Imp” means the importance of teaching the corresponding idea about science. \( ^{c} \)“Teaching” means the participant’s description of his or her action or plan for teaching the corresponding idea about science. In the appropriateness and importance column, the number presents the participant’s degree of agreement regarding each idea about science from 1 (not at all appropriate/important) to 5 (very appropriate/important) while the letter presents the participant’s placement of the idea at the bottom (B), middle (M), or top (T) of his or her list when s/he compared the nine ideas about science in terms of their developmental appropriateness or importance at their grade level. \( ^{d} \)The participant changed the rating for the corresponding idea during the interview.
Post-NOS Training Beliefs

This section consists of two sub-sections. First, it present the findings obtained from the analysis of each participant’s post-NOS training beliefs about the developmental appropriateness and importance of teaching the nine NOS aspects. Second, it presents the findings obtained from the cross-case analysis of the participants’ post-NOS training beliefs about the developmental appropriateness and importance of teaching the nine NOS aspects at their grade level.

Francine’s Post-NOS Training Beliefs

After the NOS training, Francine did not change her beliefs about the developmental appropriateness and importance of teaching the nine ideas about science because she gave the same ratings for each idea about science as seen in Table 6. Francine continued to believed that it is “very appropriate/important” to teach the inferential, creative, tentative, empirical, subjective, socio-cultural, collaborative NOS aspects and the absence of the scientific method while “neither appropriate/important nor inappropriate/unimportant” to teach the bounded NOS aspect at the third grade level.

Even though Francine’s beliefs about the developmental appropriateness and importance of each idea about science did not change after the NOS training, her confidence in those beliefs changed for certain NOS aspects. Francine explicitly expressed during her follow-up interview that her beliefs about the developmental appropriateness and/or importance become stronger for the inferential, creative, and tentative NOS aspects and the absence of a single step-by-step scientific method because she felt that she had a better understanding of these NOS aspects. The following paragraphs present Francine’s post-NOS training beliefs about these four NOS aspects.
After the NOS training, Francine strengthened her beliefs about not only developmental appropriateness but also importance of teaching the difference between observation and inference. Even though Francine continued to rate teaching the inferential NOS as “very appropriate” to teach at the third grade, she no longer mentioned that her third graders could have difficulty in making inference. Rather, she noted on her questionnaire “third graders could understand the difference between inference and observation”. This change in her beliefs about the developmental appropriateness of teaching the inferential NOS seemed to support her beliefs about the importance of teaching this NOS aspect because she explained her rating about the importance of teaching the inferential NOS with the developmental appropriateness of the inferential NOS: “very important [to teach the inferential NOS aspect] because third graders can understand the difference between inference and observation” [Post-NOS training beliefs questionnaire]. In addition, Francine acknowledged the influence of her better understanding of the inferential NOS aspect on her beliefs about the importance of teaching this idea as follow: “I still believe, but after our training become more clear what is inference, what is observation for me as well. So, I still believe it is very important and students need to know the importance of inference and observation” [post-NOS training beliefs interview].

In addition to the inferential NOS aspect, Francine strengthened her beliefs about the importance of teaching the idea that science is a creative process at the end of the NOS training. During the follow-up interview, Francine continued to express that she already saw from her science learning and teaching experience that it is very important to nurture students’ creativity in order to promote their science learning. Therefore, the NOS
training once again showed what she already believed about the importance of teaching the creative NOS aspect is right because she started to consider creativity as an integral part of scientists’ work after the NOS training. The following excerpt indicates the influence of Francine’s better understanding of the creative NOS aspect on her beliefs about the importance of teaching this idea.

It is very important because sometimes kids think that science is all about facts and data. You can’t use the creativity or other things, but it is all about the creativity. So, I think if they learn the creativity is the part of the science and also we are using it every step, it is going to encourage them to have better ideas. They will be more brave to sharing their ideas or having different ideas, having different prediction, having different hypotheses. If you don’t teach them science is a creative process, they will try to find some information from encyclopedia or from the Internet and try to copy and paste. They will not have any room for their creativity [post-NOS training beliefs interview].

In her post-NOS training explanation, Francine talked about the importance of promoting students’ philosophical understanding of the role of creativity and imagination in science for nurturing their creativity and then promoting their science learning. On the other hand, at the beginning of the NOS training she just focused on nurturing students’ creativity.

The tentative NOS aspect is another idea about science that Francine found very important to teach not only at the beginning but also at the end of the NOS training. However, Francine felt that learning more about the tentative NOS aspect throughout the
NOS training made her beliefs about the importance of teaching this idea stronger. The following excerpt presents the evidence of Francine’s strengthened beliefs about the importance of teaching the tentative NOS aspect at the third grade.

I always believed that science is tentative and we need to teach that, but after our training, especially with the Tangram activity like you have new evidence and everything just changed and you are trying. So, I believed, I was believing it is 5 out of 5. It is very important, but I think I believed with all my heart after our training [post-NOS training beliefs interview].

The last idea about science that Francine felt her beliefs were strengthened was the absence of a single step-by-step scientific method. During the post-NOS training follow-up interview, Francine acknowledged that she gave her initial rating with a misconception about “the scientific method” by stating “we used to teach about scientific method and students used to feel they have to follow the certain steps and if they make mistakes they need to start all over again” [post-NOS training beliefs interview]. After having realized her misconception about the scientific method, she found teaching the existence of multiple scientific methods important to clear her students’ misconception about the scientific method: “I know it is important, but after your training I believed more. My belief is more strong that science is not really the scientific method” [post-NOS training beliefs interview].

Even though Francine did not change her ratings for the developmental appropriateness and importance of teaching the ideas about science after the NOS training, she switched the bottom and top ideas while comparing their developmental
appropriateness and importance (See Table 6). For instance, Francine started to consider the creative and tentative NOS aspects among the most appropriate and important ideas about science rather than the least important ones. Similarly, she placed the developmental appropriateness and importance of the idea about the absence of a single scientific method from the top of her list to the bottom of her list at the end of the NOS training. During the follow-up interview, Francine related this change in her rankings with her better understandings of the NOS aspects rather than a change in her beliefs about the developmental appropriateness and importance of the NOS aspects as follows.

When you start the training, I really even had a hard time to say inferential and empirical. So, not more than the meaning even with the vocabulary to say had a hard time. So, I just maybe randomly put them like how I understood. May be my comprehension changed. I still have the same ideas maybe, but since my comprehensions got better on those NOS [post-NOS training beliefs interview].

In other words, after the NOS training Francine felt that she was better able to assess to what extent her third graders could grasp the NOS aspects and they could get benefits from learning about them because she learned more about NOS aspects. As a better assessor of the developmental appropriateness and importance of the NOS aspects, her individual and relative ratings were more consistent than before.
Table 6
Francine’s Pre- and Post-NOS Training Ratings for the Developmental Appropriateness and Importance of Teaching Ideas about Science for her Third Graders

<table>
<thead>
<tr>
<th>Idea about science</th>
<th>Applicability</th>
<th>Importance</th>
<th>Teaching</th>
</tr>
</thead>
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<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>Inferential NOS</td>
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<td>5/6</td>
<td>5/6d</td>
</tr>
<tr>
<td>Creative NOS</td>
<td>5/9</td>
<td>5/1</td>
<td>5/9</td>
</tr>
<tr>
<td>Tentative NOS</td>
<td>5/8</td>
<td>5/2</td>
<td>5/8</td>
</tr>
<tr>
<td>Empirical NOS</td>
<td>5/1d</td>
<td>5/4</td>
<td>5/1d</td>
</tr>
<tr>
<td>Subjective NOS</td>
<td>5/7</td>
<td>5/3</td>
<td>5/7</td>
</tr>
<tr>
<td>Socio-cultural NOS</td>
<td>5/7</td>
<td>5/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Scientific Methods</td>
<td>5/2</td>
<td>5/8</td>
<td>5/2</td>
</tr>
<tr>
<td>Collaborative NOS</td>
<td>5/3</td>
<td>5/7</td>
<td>5/3</td>
</tr>
</tbody>
</table>

Note. The first number in each cell shows the participant’s degree of agreement regarding the developmental appropriateness or importance of the idea from 1 (not at all appropriate/important) to 5 (very appropriate/important). The second number in each cell presents the participant’s rank for the developmental appropriateness or importance of the idea, ranging from 1 representing “the most appropriate/important idea about science” to 9 representing “the least appropriate/important idea about science”. The participant switched her ratings for the empirical and inferential NOS aspects because she could not differentiate between the provided definitions of these two NOS aspects.

Anna’s Post-NOS Training Beliefs

Anna did not show significant changes in her beliefs about the developmental appropriateness and importance of teaching the NOS aspects after the NOS training because she gave very similar ratings for each NOS aspect on her pre- and post-NOS training questionnaires (See the first numbers in Table 7). Consistently, during the post-NOS training follow-up interview Anna explicitly expressed that her beliefs either stayed the same or slightly changed. For instance, she started to see the idea about the absence of a single step-by-step scientific method as “somewhat appropriate” and “somewhat important” rather than “very appropriate” and “very important” to teach at the fifth grade.
After the NOS training, Anna continued to believe that none of the NOS aspects are unimportant or inappropriate to teach, but some of them (e.g., the bounded NOS aspect) are less appropriate or important to teach at the fifth grade level. The following two paragraphs indicate which NOS aspects Anna considered relatively less appropriate and important.

Among the nine NOS aspects, Anna believed not only at the beginning but also at the end of the NOS training that it is not very appropriate to teach the collaborative, subjective, and bounded NOS aspects at the fifth grade level. She expressed during the follow-up interview that it is hard for her fifth graders to understand the collaborative NOS aspect because they tended to “rip each other apart once you tell them that they can critically review something” [post-NOS training beliefs interview]. Similarly, she continued to feel that her students are not ready to grasp the subjective and bounded NOS aspects because “they are still at a more concrete stage of learning at this age” [post-NOS training beliefs interview] and they had a worldview rejecting the existence of multiple truths. The following excerpt indicates how Anna explained the influence of her fifth grade students’ worldview on their understanding of the subjective NOS aspect.

I think I meant on both [pre- and post-NOS training] that [the subjective NOS aspect] is somewhere in between there because like I said they may take this concept to the extreme. At this age group if you give them a little they would take this much. So, it is hard for them put things into perspectives when you talk about this means personal values, prior knowledge, and experience. They will argue it to a certain point and, you know, just to prove their point. It is so hard to explain like with these kids. You can describe for them that yes the scientist, even we knew
that, like in our science book, they think this and this one thinks this because of their own reasons, but they will either do, what these kids did, and say No, I need to know which one right. I want to know what is right now. It can’t both be it is thinking something different or they will say well, you know I think this because my prior experience [post-NOS training beliefs interview].

After the NOS training, Anna continued to think that among the nine NOS aspects it is not very important to teach the subjective, bounded, and creative NOS aspects at the fifth grade. As for the subjective and bounded NOS aspects, she still did not want to spend so much time because she thought that her students would face with difficulties in understanding these NOS aspects as described in the previous paragraph. Anna also did not want to allocate so much time on teaching the idea that science is a creative process because she continued to think that her students are inherently creative.

Even though Anna continued to believe that all of the NOS aspects, even the bounded NOS aspect, are appropriate and important to teach at the fifth grade, she felt more confidence in her assessment about to what extent these NOS aspects are appropriate or important to teach at the fifth grade because she thought that she had a better understanding of the NOS aspects after the NOS training. The following excerpt provides an evidence of Anna’s strengthened beliefs about the importance of teaching the NOS aspects.

The more I learned about them, the more I become picky…I thought this is really what they need right now at this time as prior them I might have been like yeah,
yeah they need it all. They kind of have all of it [post-NOS training beliefs interview].

As an another evidence for Anna’s strengthened beliefs about the developmental appropriateness of teaching the NOS aspects, it became clearer for her that it is not very appropriate to teach the bounded NOS aspect at the fifth grade level because Anna felt that even she could not understand this NOS aspect fully after the NOS training.

As a better assessor of the developmental appropriateness and importance the NOS aspects, Anna gave more consistent ratings that reflect her beliefs. For instance, not only at the beginning but also at the end of the NOS training she believed that her fifth graders would have difficulty in understanding only the subjective and bounded NOS aspects. At the beginning of the NOS training she put other NOS aspects she found more appropriate than the subjective and bounded NOS aspects to the bottom of her list. However, after the NOS training she placed these two NOS aspects at the bottom of her list (See Table 7). Supportively, she mentioned only for the subjective and bounded NOS aspects that she did not plan to teach them by the end of the semester because her students would not have enough time to understand these difficult concepts.
Table 7
Anna’s Pre- and Post-NOS Training Ratings for the Developmental Appropriateness and Importance of Teaching Ideas about Science for her Fifth Graders

<table>
<thead>
<tr>
<th>Idea about science</th>
<th>Appropriateness</th>
<th>Importance</th>
<th>Teaching</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>Inferential NOS</td>
<td>5/1</td>
<td>5/3</td>
<td>5/1</td>
</tr>
<tr>
<td>Creative NOS</td>
<td>4/8</td>
<td>4/7</td>
<td>5/8</td>
</tr>
<tr>
<td>Tentative NOS</td>
<td>5/2</td>
<td>5/2</td>
<td>5/2</td>
</tr>
<tr>
<td>Empirical NOS</td>
<td>4/9</td>
<td>5/1</td>
<td>5/9</td>
</tr>
<tr>
<td>Subjective NOS</td>
<td>4/4</td>
<td>3/8</td>
<td>2/4</td>
</tr>
<tr>
<td>Socio-cultural NOS</td>
<td>5/7</td>
<td>5/6</td>
<td>5/7</td>
</tr>
<tr>
<td>Scientific Methods</td>
<td>5/3</td>
<td>4/4</td>
<td>5/3</td>
</tr>
<tr>
<td>Collaborative NOS</td>
<td>4/6</td>
<td>4/5</td>
<td>5/6</td>
</tr>
<tr>
<td>Bounded NOS</td>
<td>4/5</td>
<td>3/9</td>
<td>4/5</td>
</tr>
</tbody>
</table>

Note. The first number in each cell shows the participant’s degree of agreement regarding the developmental appropriateness or importance of the idea from 1 (not at all appropriate/important) to 5 (very appropriate/important). The second number in each cell presents the participant’s rank for the developmental appropriateness or importance of the idea, ranging from 1 representing “the most appropriate/important idea about science” to 9 representing “the least appropriate/important idea about science”. The participant changed the rating for the corresponding idea during the interview.

Nancy’s Post-NOS Training Beliefs

Nancy did not show significant quantitative changes in her beliefs about the developmental appropriateness and importance of the NOS aspects after the NOS training because she gave very similar ratings for each NOS aspect on her pre- and post-NOS training questionnaires (See Table 8). However, Anna showed some qualitative changes in her beliefs about the developmental appropriateness and importance of the NOS aspects after the NOS training. Anna felt that her beliefs were enhanced because she had a better understanding of the NOS aspects after the NOS training. For instance, not only at the beginning but also at the end of the NOS training Nancy rated the creative NOS aspect as “very important” to teach at the fifth grade (See Table 8). However, she
believed more in the importance of teaching the creative NOS aspect at the end of the NOS training because she came to realize that science is more creative than she thought before. The following excerpt presents an evidence of Nancy’s strengthened beliefs about the importance of teaching the creative NOS aspect after the NOS training.

I think that I knew before that it was important, but I think that I genuinely feel that you know, how much it’s – how important it is now because I understand the whole like what a creative process it is, whereas before I just kind of, you know, thought it probably was, but I really understand it more now [post-NOS training beliefs interview].

Unlike the creative NOS aspect, Nancy showed both quantitative and qualitative changes in her beliefs about the developmental appropriateness and importance of teaching the inferential NOS at the fifth grade level. After the NOS training, she moved up her ratings for teaching the inferential NOS aspect from “somewhat appropriate” and “somewhat important” to “very appropriate” and “very important”, respectively. Moreover, Nancy acknowledged during her post-NOS teaching interview that the NOS training helped her to realize the appropriateness and importance of teaching the inferential NOS aspect because she was able to clarify the distinction between observation and inference at the end of the NOS training.

After the NOS training, Nancy also felt more confident that all of the NOS aspects are appropriate or important to teach, though some of them (e.g., socio-cultural, collaborative, and bounded NOS aspects) are less appropriate or important to teach at the fifth grade. For instance, both at the beginning and at the end of the NOS training Nancy
raised concerns about the importance of teaching the idea that science cannot answer questions related to art, philosophy, ethics, or religion because she felt that her fifth graders would have difficulty in understanding the abstract terms such as ethics and philosophy. However, after the NOS training, Nancy believed even less in the importance of teaching bounded NOS aspect because she much more appreciated the importance of teaching the other NOS aspects as seen in the following excerpt.

The researcher: So, do you think your rating [for the bounded NOS aspect] changed compared to the beginning one?
Nancy: I think it might have changed. It might have changed only because I think after looking at all the other ones more closely, I thought – I really realized, you know, how important the other ones were to me, and that just made this one [the bounded NOS aspect] less important than it might have started out as [post-NOS training beliefs interview].

In other words, after the NOS training it became clearer for Nancy that teaching the bounded NOS aspect was relatively less important or appropriate than teaching other NOS aspects. This seemed to be supported by the changes not only in her placement of the bounded NOS aspect among the nine NOS aspects but also in her description of her action or plan for teaching the bounded NOS aspect. Nancy placed the bounded NOS aspect at the bottom instead of the middle of her list at the end of the NOS training. Moreover, she became sure that she did not plan to teach the bounded NOS aspect by the end of the semester (See Table 8 for Nancy’s pre- and post-NOS training placements of the nine NOS aspects in terms of their developmental appropriateness and importance to
teach at the fifth grade level and for her pre- and post-NOS training descriptions of action or plan for teaching the nine NOS aspects).

Table 8

Nancy’s Pre- and Post-NOS Training Ratings for the Developmental Appropriateness and Importance of Teaching Ideas about Science for her Fifth Graders

<table>
<thead>
<tr>
<th>Idea about science</th>
<th>Pre Appropriateness</th>
<th>Importance</th>
<th>Teaching</th>
<th>Post Appropriateness</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inferential NOS</td>
<td>4/3</td>
<td>5/2</td>
<td>4/2</td>
<td>5/2</td>
<td></td>
</tr>
<tr>
<td>Pre NOS</td>
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<td>5/3</td>
<td>5/7</td>
<td>5/3</td>
<td></td>
</tr>
<tr>
<td>Tentative NOS</td>
<td>5/8</td>
<td>5/5</td>
<td>5/8</td>
<td>5/5</td>
<td></td>
</tr>
<tr>
<td>Empirical NOS</td>
<td>5/2</td>
<td>5/1</td>
<td>5/3</td>
<td>5/1</td>
<td></td>
</tr>
<tr>
<td>Subjective NOS</td>
<td>5/5</td>
<td>5/4</td>
<td>5/4</td>
<td>5/4</td>
<td></td>
</tr>
<tr>
<td>Socio-cultural NOS</td>
<td>5/6</td>
<td>5/7</td>
<td>5/5</td>
<td>5/7</td>
<td></td>
</tr>
<tr>
<td>Scientific Methods</td>
<td>5/1</td>
<td>5/6</td>
<td>5/1</td>
<td>5/6</td>
<td></td>
</tr>
<tr>
<td>Collaborative NOS</td>
<td>5/9</td>
<td>5/8</td>
<td>5/9</td>
<td>5/8</td>
<td></td>
</tr>
</tbody>
</table>

Note. The first number in each cell shows the participant’s degree of agreement regarding the developmental appropriateness or importance of the idea from 1 (not at all appropriate/important) to 5 (very appropriate/important). The second number in each cell presents the participant’s rank for the developmental appropriateness or importance of the idea, ranging from 1 representing “the most appropriate/important idea about science” to 9 representing “the least appropriate/important idea about science”. aThe participant changed the rating for the corresponding idea during the interview.

In addition to feeling more confident in her pre-existing beliefs about the developmental appropriateness and importance of the NOS aspects, Nancy believed that she assessed the developmental appropriateness and importance of the NOS aspects more accurately at the end of the NOS training by stating “I think that, probably all of my thoughts about these being important probably increased a little bit just from the training and everything and from my experience teaching, um, because I had no clue before” [post-NOS training beliefs interview]. In other words, after having better understandings
of the NOS aspects plus science teaching experience over the last couple months, Nancy believed that she started to develop a basis to make decisions about the developmental appropriateness and/or importance of the NSO aspects.

**Andy’s Post-NOS Training Beliefs**

After the NOS training, Andy did not show significant changes in his beliefs about the developmental appropriateness and importance of the NOS aspects because he continued to consider all of the NOS aspects, even the bounded NOS aspect as appropriate and important to teach at the fifth grade level (See Table 9 for detailed information about Andy’s ratings for each NOS aspect). Even if he gave different ratings for certain NOS aspects, Andy substantiated during the follow-up interview that they were not totally related to the NOS training. As seen in the following excerpt, he thought that some of his ratings or rankings might not be the same because he had a different mood as filling out the pre- and post-NOS training surveys.

> In the beginning of the year, you are thinking of like we have to make sure we do this, this, and this and then, you know, this is more towards the end of the year. So then you go, okay, this is not a problem for them. They do understand this. They mostly get it before even come here, but you still want to spend your time ensuring that they get it [post-NOS training beliefs interview].

In other words, Andy believed that his pre-NOS training ratings or rankings might not be so precise. However, he highlighted during the follow-up interview that he trusted more in his post-NOS training ratings or rankings because he found them more meaningful than before. In other words, after the NOS training Andy felt more confident in what
kinds of ideas his students are expected to know about science. He strongly believed that he should give his students a chance to learn about each of the nine NOS aspects.

As making decisions about the developmental appropriateness and importance of the NOS aspects, Andy claimed that he used a different logic than before. Accordingly, he rated or ranked a certain NOS aspect as more appropriate if he thought that his students could see the examples of this particular NOS aspect in the science curriculum and they could easily understand that particular NOS aspect. On the other hand, Andy rated or ranked a certain NOS aspect as less appropriate if he believed that understanding of that particular NOS aspect requires a higher level thinking that only a few students could think on that level or his students had a lot of or no exposure to that particular NOS aspect in their science curriculum. As for the importance of the NOS aspects, Andy believed that a certain NOS aspect could not be as high in priority if it is really beyond his students’ level of understanding or if his students already knew or been exposed to that particular NOS aspect.

Even though Andy believed that he used a different reasoning in his assessment of the developmental appropriateness of the NOS aspects, he came up with the same top three NOS aspects as seen in Table 9. After the NOS training, Andy continued to believe that the inferential, empirical, and tentative NOS aspects were the most appropriate ideas about science to teach at the fifth grade level. He expressed during the follow-up interview that the inferential NOS aspect is very appropriate to teach at the fifth grade level because “students have had a lot of exposure to it already in the other grades” [post-NOS training beliefs interview]. After the inferential NOS aspect, Andy thought teaching the empirical NOS aspect very appropriate for his fifth graders because “it is a concrete
idea that they understand and have many examples” [post-NOS training beliefs questionnaire]. Similarly, Andy considered the tentative NOS aspect very appropriate to teach at the fifth grade level because “there are tons of examples of this in their book” [post-NOS training beliefs interview].

Unlike the top three NOS aspects, Andy slightly changed his rankings for the bottom NOS aspects when he compared the developmental appropriateness of the nine NOS aspects. After the NOS training, Andy started to consider the absence of a single step-by-step scientific method among the least appropriate idea about science. As I targeted in the NOS training, he acknowledged that it is important to teach his students that science is not so rigid. However, he believed that such understanding is not possible without teaching the step-by-step scientific method as seen in the following excerpt.

This one I would say that this – not a single step for the scientific method, I think it is, first of all, it is somewhat appropriate because they have to understand the basics before they can understand, oh, you don’t always have to follow this pattern. So, the fact that they understand at least the basic pattern, once that’s established and those intelligent kids that can think on this level then you can say, hey, it is okay to sometimes break the rule a little bit. That’s fine, and I think that that’s the balance you have to strike is that for those kids who can handle it, it’s a great thing to introduce to them, but for those kids who can’t it’s too confusing because you don’t want them to have this idea that there are no rules…So, you don’t want them to have this idea that, well, there’s no rules, and it doesn’t matter. You just do whatever you want because that would be a very bad idea for them to
get, but once they understand the basics, I think it’s fine for them to say, okay, you can be flexible within this process [post-NOS training beliefs interview].

In other words, Andy believed that he first needed to teach the step-by-step scientific method and then he could teach his students that there are more than one ways to do science. Otherwise, he could convey another misconception about science that ‘do whatever you want’ [post-NOS training beliefs questionnaire].

Not only at the beginning but also at the end of the NOS training, Andy believed that the collaborative and bounded NOS aspects were the least two appropriate ideas about science to teach at the fifth grade level. He once again thought that the bounded NOS aspect was not very appropriate to teach at the fifth grade level because “it is a higher level concept that only advanced students would really consider” [post-NOS training beliefs questionnaire]. Unlike the bounded NOS aspect, Andy considered the collaborative NOS aspect relatively less appropriate to teach because “students understand this idea quite well before they start the 5th grade” [post-NOS training beliefs questionnaire].

The NOS training seemed to contribute more to Andy’s beliefs about the importance of teaching the NOS aspects as compared to his beliefs about the developmental appropriateness because at the end of the NOS training he changed his ratings or rankings for almost all of the NOS aspects (See Table 9). After the NOS training, Andy started to consider teaching the creative, subjective, and socio-cultural NOS aspects as the most three important ideas about science. He believed that it is very important to teach these three NOS aspects because they are important elements of science based on the targets of the NOS training. However, his students did not have
enough or accurate knowledge about them because of the lack of explicit exposure to these NOS aspects in their textbooks or in their science lessons. The following excerpt illustrates this point for the creative NOS aspect.

The researcher: When I look at your previous response, you gave 4 [somewhat important], but this time you said it is very important to teach. So, how do you explain this change?

Andy: Well, I think that again, it’s sort of what we’ve been going over, I see this is something that they really lack. So, it’s important that we put some time into it.

The researcher: So, this comes from your teaching experience?

Andy: I think so. Both. Both the experience in the class this year and just, in general, that this is something that they lack exposure to and lack understanding. So, of course, it should be high on our list.

The researcher: Okay. So, it is not related to our training?

Andy: No, I think it is. That’s what I’m saying. I think it is related to the training because I’m seeing that, okay, this is something that they should know, and they don’t really know this. This is something that they need to be exposed to, you know [post-NOS training beliefs interview].

Among the least three important NOS aspects, Andy kept only the bounded NOS aspect at the end of the NOS training because he continued to think that it is not very important to teach something that only a few of his students could fully understand. In addition to the bounded NOS aspect, Andy placed the absence of a single step-by-step scientific method and collaborative NOS aspects at the bottom of his list at the end of the
NOS training (See Table 9 for the pre- and post-NOS training rankings of the nine NOS aspects). Unlike his pre-NOS training rankings, he gave more priority to teach the subjective and sociocultural NOS aspects at the end of the NOS training because he perceived that these two NOS aspects are not presented in his students’ textbooks.

Table 9  
*Andy’s Pre- and Post-NOS Training Ratings for the Developmental Appropriateness and Importance of Teaching Ideas about Science for his Fifth Graders*

<table>
<thead>
<tr>
<th>Idea about science</th>
<th>Appropriateness</th>
<th>Importance</th>
<th>Teaching</th>
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<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>Inferential NOS</td>
<td>4/1</td>
<td>5/1</td>
<td>5/1</td>
</tr>
<tr>
<td>Creative NOS</td>
<td>4/6</td>
<td>4/4</td>
<td>4/6</td>
</tr>
<tr>
<td>Tentative NOS</td>
<td>5/3</td>
<td>5/3</td>
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</tr>
<tr>
<td>Empirical NOS</td>
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<tr>
<td>Subjective NOS</td>
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<tr>
<td>Socio-cultural NOS</td>
<td>5/4</td>
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</tr>
<tr>
<td>Scientific Methods</td>
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<tr>
<td>Collaborative NOS</td>
<td>5/9</td>
<td>5/8</td>
<td>5/4</td>
</tr>
<tr>
<td>Bounded NOS</td>
<td>3/8</td>
<td>4/9</td>
<td>3/9</td>
</tr>
</tbody>
</table>

*Note.* The first number in each cell shows the participant’s degree of agreement regarding the developmental appropriateness or importance of the idea from 1 (not at all appropriate/important) to 5 (very appropriate/important). The second number in each cell presents the participant’s rank for the developmental appropriateness or importance of the idea, ranging from 1 representing “the most appropriate/important idea about science” to 9 representing “the least appropriate/important idea about science”. *a* The participant changed the rating for the corresponding idea during the interview.

**Cross Case Analysis of Post-NOS Training Beliefs**

The cross-case analysis revealed that none of the participants showed significant differences in their beliefs about the developmental appropriateness and importance of the NOS aspects (See Table 10 for detailed information about the changes in the participants’ beliefs). They continued to think that all NOS aspects even the bounded
NOS aspects are both appropriate and important to teach at the elementary level. However, they considered some NOS aspects are relatively less appropriate or important. Among the nine NOS aspects, all teachers, regardless of their grade level, had doubts about the appropriateness and importance of teaching certain parts of the bounded NOS aspect. They all agreed that elementary students could understand that scientists cannot answer all questions, but students would face a difficulty in understanding the reasons why religious, ethical, and moral questions could not be answered by science.

Second, all participants felt more confident in their ability to rate and rank the NOS aspects in terms of their appropriateness and importance because they felt that they improved or clarified their understandings of the NOS aspects after the NOS training. Therefore, they thought that their ratings and ranking of the NOS aspects were more precise and accurate compared to their pre-NOS training ratings and rankings.

Finally, five factors played a significant role in the elementary teachers’ assessment of the NOS aspects in terms of their appropriateness and importance: (1) the teachers’ perception of the student ability at a particular grade level, (2) the alignment between the content of the NOS training and the teachers’ pre-existing beliefs about teaching NOS, (3) the changes in the teachers’ sophistication of NOS understandings, (4) the teachers’ knowledge about the possible student misconceptions about NOS, and (5) the teachers’ perceptions about the presence of the NOS aspects in their curriculum.

First, the teachers considered their students’ grade and ability level when making decisions about appropriateness and importance of each specific NOS aspect. For instance, Andy contemplated to teach the bounded NOS aspect in his high achieving fifth grade class; even though, he considered this specific aspect as the least appropriate for
regular fifth grade students. All of the other fifth grade teachers did not consider teaching the bounded NOS aspect due to their students’ lack of ability to understand the complexities of this particular aspect. Francine considered teaching the bounded NOS aspect in her own class if she were to teach fifth graders. She thought that understanding the bounded NOS aspect was beyond the capabilities of her third graders. As seen in the following excerpt, one of our participants (Andy) explained in his own words how the teachers’ perception about their students’ grade and ability level influenced their beliefs about the developmental appropriateness or importance of teaching the NOS aspects.

The researcher: Do you have any suggestion for a teacher educator that how we can change teacher beliefs about, you know, it is important to teach these aspects or it is appropriate to teach these ideas?

Andy: I would say in general, as you know I think, I probably said many times when we were going through this [interview] where I know that other people teach different kids or different levels of kids in a grade or younger children. They can’t do this – why are we already judging they can’t do it? I mean, you can say, okay, I maybe won’t spend so much time on this or maybe I won’t make this a focus, but why are we denying them the opportunity to put, you know, like a lot of times you have to give them the opportunity to show they can handle something besides – instead of just assuming right away, oh, they can’t do this. This is too hard for them, you know [post-NOS training beliefs interview].

Second, the teachers reconsidered their assessment about the developmental appropriateness and importance of the NOS aspects if they felt that their pre-existing
beliefs about teaching the NOS aspects were not so aligned with the content of the NOS training. For instance, at the beginning of the NOS training all of the participants believed that it is very appropriate and very important to teach the idea that there is no single step-by-step scientific method by which all science is done. However, after the NOS training they all started to raise doubts about the developmental appropriateness or importance of teaching the absence of a step-by-step scientific method because they believed that their students first needed to learn this step-by-step scientific method. After their students developed this basic, but distorted, understanding about the scientific method, they believed that they could teach that there are more than one ways to do science. In other words, they first wanted to teach the myth of the scientific method and then revise it with more accurate understanding of the presence of multiple scientific methods.

Third, teachers sometimes assessed the developmental appropriateness and importance of NOS aspects by considering how well they learned a particular NOS aspect. For instance, both Nancy and Francine felt that they made significant improvements in their understanding of the creative NOS aspect after the NOS training. They placed the creative NOS aspect at the bottom of the list when they were asked to rank the NOS aspects in terms of appropriateness and importance at the beginning of the NOS training. However, they moved the creative NOS aspect from the bottom of the list to the top of the list when they ranked the NOS aspects at the end of the NOS training. I think that they changed the ranking of the creative NOS aspect because they had a more sophisticated understanding about this particular NOS aspect at the end of the NOS training. Unlike Nancy and Francine, Anna felt that she did not make significant
improvement in her creative NOS understanding. Therefore, I think that she did not change the ranking of her creative NOS aspect at the end of the NOS training.

Fourth, the teachers considered certain NOS aspects as more appropriate and important to teach if they thought that their students held misconceptions about these particular NOS aspects. For instance, after the NOS training Andy started to articulate that some of his students held misconceived notions of the creative and socio-cultural NOS aspects. This articulation led Andy to consider spending more class time on these two NOS aspects to introduce the appropriate understandings of these NOS aspects. Similarly, after the NOS training Francine started to mention that some of her students held naïve conceptions that “science is all about facts and data” [post-NOS training beliefs interview]. After having realized this misconception about the creative NOS aspect Francine changed her ranking of the creative NOS in terms of appropriateness and importance. She moved the creative NOS aspect from the bottom of her ranking list to the top of her list. This shows that the more the teachers know about their students misconceptions the more they prioritize to teach certain NOS aspects to address these misconceptions.

Finally, the teachers sometimes made decisions about the developmental appropriateness or importance of a certain NOS aspect based on to what extent that particular NOS aspect was included in their curriculum. For instance, all of the teachers continued to emphasize the importance of the science fair projects in their science curriculum at the school. Therefore, they once again considered teaching the absence of a single step-by-step scientific method appropriate and important at the elementary level because they believed that having more sophisticated understanding of the absence of a
single step-by-step scientific method would enhance their students’ performance in science fair projects. In other words, all of them believed that teaching the absence of a single step-by-step scientific method is already present in their science curriculum. Unlike the absence of a single step-by-step scientific method, Andy believed that his students did not have a lot of exposure to the creative and subjective NOS aspects because their science textbooks do not explicitly explain these two NOS aspects. Rather, they just focused on the facts in science. Supportively, he believed that it is very important to teach the socio-cultural NOS aspect because he remembered a question in the CRT examination that required their students to know that “science has been practiced all around the world through many generations of people” [post-NOS training beliefs interview]. These examples indicate that the more the teachers think that a particular NOS aspect has practical implications the more they tend to teach that particular NOS aspect.

Overall, I did not realize major quantitative changes in the elementary teachers’ beliefs about the developmental appropriateness and importance of teaching the nine NOS aspects. However, I was able to identify qualitative changes in the teachers’ beliefs at the end of the NOS training.
Table 10
The Participants’ Pre- and Post-NOS Training Ratings for the Developmental Appropriateness and Importance of Teaching the Nine Ideas about Science

<table>
<thead>
<tr>
<th>Idea about science</th>
<th>Francine</th>
<th>Anna</th>
<th>Nancy</th>
<th>Andy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PreA&lt;sup&gt;a&lt;/sup&gt;</td>
<td>PostA&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Pref&lt;sup&gt;c&lt;/sup&gt;</td>
<td>PostI&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Inferential</td>
<td>5/M&lt;sup&gt;e&lt;/sup&gt;</td>
<td>5/M</td>
<td>5/M&lt;sup&gt;e&lt;/sup&gt;</td>
<td>5/T</td>
</tr>
</tbody>
</table>

Note. <sup>a</sup>“PreA” means the participant’s rating or ranking about the developmental appropriateness of the idea at the beginning of the NOS training. <sup>b</sup>“PostA” means the participant’s rating or ranking about the developmental appropriateness of the idea at the end of the NOS training. <sup>c</sup>“PreI” means the participant’s rating or ranking about the importance of the idea at the beginning of the NOS training. <sup>d</sup>“PostI” means the participant’s rating or ranking about the importance of the idea at the end of the NOS training. In the appropriateness and importance columns, the number presents the participant’s degree of agreement regarding each idea about science from 1 (not at all appropriate/important) to 5 (very appropriate/important), while the letter presents the participant’s placement of the idea at the bottom (B), middle (M), or top (T) of his or her list when s/he compared the nine ideas about science in terms of their developmental appropriateness or importance at their grade level. <sup>e</sup>The participant changed the rating for the corresponding idea during the interview.
Post-NOS Teaching Beliefs

This section consists of two sub-sections. First, it present the findings obtained from the analysis of each participant’s post-NOS teaching beliefs about the developmental appropriateness and importance of teaching the nine NOS aspects. Second, it presents the findings obtained from the cross-case analysis of the participants’ post-NOS teaching beliefs about the developmental appropriateness and importance of teaching the nine NOS aspects at their grade level.

Francine’s Post-NOS Teaching Beliefs

Francine did not show significant changes in her beliefs about the developmental appropriateness and importance of teaching the NOS aspects after teaching several NOS lessons (See Table 11 for Francine’s ratings or rankings of developmental appropriateness and importance for each NOS aspect). Among the nine NOS aspects, she made only slight changes in her ratings for the developmental appropriateness and importance of teaching the absence of the step-by-step scientific method at the third grade. Francine already raised some concerns about the developmental appropriateness and importance of teaching the absence of a step-by-step scientific method after the NOS training. However, she seemed to have more strengthened concerns about this particular NOS aspect after her NOS teaching experience because Francine started to rate teaching the absence of a single step-by-step scientific method as “somewhat appropriate/important” rather than “very appropriate/important”. The following excerpt presents Francine’s explanation for why she changed her ratings for the absence of a single step-by-step scientific method.
because after each activity I was asking them what do you think which aspects of NOS we saw here? Only a few kids were saying the scientific method, but not a lot. So, a few kids when they look at the chart they remember oh, this is scientific method, but I did not feel they really understood what the scientific method means. So, they did not pinpoint specifically oh, we saw that there is another method or something so [post-NOS training beliefs interview].

In other words, Francine saw during her NOS teaching that her students were not able to fully understand the absence of single step-by-step scientific method because they generally did not make a reference to this particular NOS aspect after the NOS activities.

Even though students’ lack of reflections on the absence of a single step-by-step scientific method after the NOS activities made Francine decrease her ratings a little bit for this particular NOS aspect, she still considered it more appropriate and important than the bounded NOS aspect. During her interview, Francine highlighted that she would not teach the bounded NOS aspect next year as well, but she would try to teach the absence of a single step-by-step scientific method next year (See Table 11 for more information about Francine’s description of her action or plan for teaching each NOS aspect). As seen in the following excerpt, Francine believed that she did not have enough evidence to claim that it is not appropriate/ important to teach the absence of a single step-by-step scientific method at the third grade level.

Francine: I was thinking like empirical, inferential those are hard vocabularies, but they understood the concept, but scientific method is an easy word, but I am not sure how much they grasped the real meaning of that, what we mean actually with the scientific method.
The researcher: So, you did not expect this before teaching?

Francine: No, I was not. I was expecting if they would fully understand, you can go easier. So, I told you I am not sure about the reason. It might be me only. I might not focus a lot as much as the other ones [other NOS aspects]. It might be also [related to] their development as well.

The researcher: What about this do you plan to teach next year the scientific method?

Francine: I think yes. I think I need to focus more to see it is really appropriate or it is not appropriate so. I need to see that [post-NOS teaching beliefs interview].

In addition to the negative feedbacks about her students’ learning outcomes, the slight change Francine showed in her beliefs about the developmental appropriateness and importance of the absence of a single step-by-step scientific method seemed to be related to her pre-existing entrenched knowledge about the scientific method.

Interestingly, when I asked Francine which NOS aspect she perceived the least growth, she pointed out the absence of a single step-by-step scientific method. As seen in the following excerpt, Francine believed that she needed more time to accommodate this particular NOS aspect because it was not consistent with her classroom practice.

We used to teach them a scientific method actually. We were getting kids for three weeks of the school to teach the scientific method. We were teaching exactly the step by step the scientific method and then suddenly you asked me do there is not one step. It is like a circle. They can go back and forth, back and forth. I understood, but I think it is going to take a little bit more time because it was not
our practice. We practiced very long time. I think I can say this one was the hardest one [post-NOS teaching beliefs interview].

In contrary to the absence of a single step-by-step scientific method, Francine continued to consider the inferential, creative, and tentative, subjective, collaborative, and sociocultural NOS aspects very appropriate and important to teach at the third grade level (See Table 11). Even though she did not change her ratings for these NOS aspects, Francine expressed during her interview that her NOS teaching strengthened her beliefs about the developmental appropriateness and importance of the NOS aspects. For instance, she explained the influence of her NOS teaching experience on teaching the inferential NOS aspect as follow: “after teaching, I said I am glad to teach because my kids enjoyed it. They had a better understanding. So, they were able to understand what observation is and what inference is… My belief did not change, but got stronger” [Post-NOS teaching beliefs interview]. Supportively, Francine continued to rank the inferential NOS aspect among the most appropriate/important idea about science because “after each activity students were saying that because science is based on observation and inference, creative or tentative, and I can say like, also the objective. These four is the most they were finding” [post-NOS teaching beliefs interview]. In other words, Francine used her NOS teaching experience as a mean to collect evidence about her students’ learning outcomes across the NOS aspects and then to check the accuracy and reliability of what she believed to be true about teaching the NOS aspects.
Table 11
Francine’s Pre-NOS Training, Post-NOS Training (Post1), and Post-NOS Teaching (Post2) Ratings and Rankings for the Developmental Appropriateness and Importance of Teaching the Ideas about Science for her Third Graders

<table>
<thead>
<tr>
<th>Idea about science</th>
<th>Appropriateness</th>
<th>Importance</th>
<th>Teaching</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post1</td>
<td>Post2</td>
</tr>
<tr>
<td>Inferential NOS</td>
<td>5/6\textsuperscript{a}</td>
<td>5/6</td>
<td>5/1\textsuperscript{b}</td>
</tr>
<tr>
<td>Creative NOS</td>
<td>5/9</td>
<td>5/1</td>
<td>5/2\textsuperscript{b}</td>
</tr>
<tr>
<td>Tentative NOS</td>
<td>5/8</td>
<td>5/2</td>
<td>5/3\textsuperscript{b}</td>
</tr>
<tr>
<td>Empirical NOS</td>
<td>5/1\textsuperscript{a}</td>
<td>5/4</td>
<td>5/5</td>
</tr>
<tr>
<td>Subjective NOS</td>
<td>5/7</td>
<td>5/3</td>
<td>5/4</td>
</tr>
<tr>
<td>Socio-cultural NOS</td>
<td>5/5</td>
<td>5/5</td>
<td>5/7</td>
</tr>
<tr>
<td>Scientific Methods</td>
<td>5/2</td>
<td>5/8</td>
<td>4/8</td>
</tr>
<tr>
<td>Collaborative NOS</td>
<td>5/3</td>
<td>5/7</td>
<td>5/6</td>
</tr>
</tbody>
</table>

Note. The first number in each cell shows the participant’s degree of agreement regarding the developmental appropriateness or importance of the idea from 1 (not at all appropriate/important) to 5 (very appropriate/important). The second number in each cell presents the participant’s rank for the developmental appropriateness or importance of the idea, ranging from 1 representing “the most appropriate/important idea about science” to 9 representing “the least appropriate/important idea about science”. \textsuperscript{a}The participant switched her ratings for the empirical and inferential NOS aspects because she could not differentiate between the provided definitions of these two NOS aspects. \textsuperscript{b}The participant had difficulty in ranking the developmental appropriateness and importance of the three NOS aspects because she considered them equally appropriate and important to teach at the third grade level.
Anna’s Post-NOS Teaching Beliefs

After teaching several NOS lesson, Anna did not feel significant changes in her beliefs about the developmental appropriateness and importance of teaching the nine NOS aspects. Rather, she thought that her beliefs were reinforced after her NOS teaching experience. She strongly believed that all of the NOS aspects, even the bounded NOS aspect, are appropriate and important to teach for her students because otherwise they could not develop an accurate view of science. With this reasoning, she rejected to rank the NOS aspects in terms of their developmental appropriateness and importance: “I don’t think I can pick one most appropriate one any more” and “there is not a most important one. There is no least important one” [post-NOS teaching beliefs interview]. Therefore, Table 12 does not present Anna’s post-NOS teaching rankings of developmental appropriateness and importance for the NOS aspects.

As for the individual ratings for the developmental appropriateness and importance of the nine NOS aspects, Anna either kept them the same or increased one point after her NOS teaching experience (See Table 12 for more information about the post-NOS teaching ratings of each NOS aspect). She highlighted during her interview that she had more evidence to support her beliefs even if she gave the same ratings for certain NOS aspects at the end of her NOS teaching. The following paragraphs explain in details the evidence that Anna collected from her NOS teaching experience to strengthen her beliefs of developmental appropriateness and importance.

One of the NOS aspects that Anna did not change her ratings of developmental appropriateness and importance was the tentative NOS aspect. Since the beginning of the professional development program, Anna rated the tentative NOS as “very appropriate”
and “very important” to teach at the fifth grade (See Table 12). However, at the end of her NOS teaching experience she expressed that she believed more in the developmental appropriateness and importance of teaching the tentative NOS aspect. Anna realized that she could have taught the tentative NOS aspect more explicitly when she covered certain science contents earlier in the semester. In other words, she thought that her science curriculum at the beginning of the semester was more conducive to teach the tentative NOS. This indicates that Anna started to develop her knowledge about when and how to teach a particular NOS aspect.

In addition to making connections between a particular NOS aspect and her science curriculum, Anna strengthened her beliefs of the developmental appropriateness and importance after making connections across certain NOS aspects. For instance, at the end of the NOS training Anna considered the empirical NOS aspect “very appropriate” and “very important” while the creative NOS aspect “somewhat appropriate” and “somewhat important” to teach at the fifth grade level (See Table 12). Unlike the empirical NOS, she believed that she did not need to focus so much on the creative NOS aspect during her science teaching because her students were already creative. During her NOS teaching, Anna realized that her students were always focusing on the creative NOS aspect without paying the required attention to empirical NOS aspect. This realization led her to feel that she needed to teach the creative NOS aspect by adhering to the empirical NOS aspect. Otherwise, her students could not differentiate scientific creativity from the artistic creativity. Therefore, after her NOS teaching experience Anna strongly believed that it is very appropriate and very important to teach not only empirical NOS aspect but also the creative NOS aspect (See Table 12).
Anna also believed more in the developmental appropriateness and/or importance of teaching a particular NOS aspect when she perceived that her students understood this particular NOS aspect more easily than she expected. Anna showed such changes in her beliefs for the subjective, collaborative, and inferential NOS aspects. For instance, after her NOS teaching Anna increased her ratings for teaching the subjective NOS aspect from “neither appropriate nor inappropriate” or “neither important nor unimportant” to “somewhat appropriate” or “somewhat important”, respectively. During the interview, she expressed this change in her ratings for the subjective NOS as follows.

It was reinforced. I believe that it is appropriate. I believe it is important, too, but I also believe that the best way to teach this is through sharing and hearing from other peoples and then talking about why one person thinks this way and the other person thinks that way and explaining what the prior knowledge is and personal experience and bringing that to like them. So, teaching that [the subjective NOS aspect] helped me see that was actually a lot easier to teach them that I thought it was going to be this concept because they pretty much get it. They picked it up and they said because I knew from this, you know what I mean, but maybe for those kids who did not get it, hearing other kids’ talking about it was, I think, the best way to teach it for them [post-NOS teaching beliefs interview].

As seen in the above excerpt, Anna believed that it was more appropriate and important to teach the subjective NOS aspect at the fifth grade because she saw that her students was able to understand the subjective NOS aspect easily when they were given an opportunity to hear different ideas and then discuss why people might think differently.

Unlike the aforementioned NOS aspects, the NOS teaching experience led Anna
to strengthen her beliefs that it was not very appropriate and very important to teach the bounded NOS aspect and the absence of a single step-by-step scientific method. As for the absence of a single step-by-step scientific method, Anna continued to rate that it was “somewhat appropriate” and “somewhat important” to teach at the fifth grade level (See Table 12). However, she expressed during her interview that her beliefs for this NOS aspect were reinforced because she did not have enough evidence to claim that her fifth graders could understand this NOS aspect fully: “I think my beliefs were reinforced. I will teach about this next, but some kids at this grade level still need that structure. If you tell them this goes in any order, their brain does not collect that so much” [post-NOS teaching beliefs interview].

Similar to the absence of a single step-by-step scientific method, Anna expressed during her post-NOS teaching interview that her students did not understand so much the bounded NOS aspect because they made a few connections to this particular NOS aspect when they reflected on the NOS activities. Moreover, Anna acknowledged that she did not focus on the bounded NOS aspect as much as the other NOS aspects during her NOS teaching. Therefore, after her NOS teaching experience Anna seemed to support her beliefs that it was “neither appropriate nor inappropriate” and “neither important nor unimportant” to teach the bounded NOS aspect at the fifth grade level (See Table 12). The following excerpt presents the evidence of her strengthened beliefs about teaching the bounded NOS aspect at the fifth grade level.

Because I did not do much with it this year, maybe next year I will touch on it and see if they create a different result in the classrooms, you know what I mean, see if they bring up more or if they make connections to it more if we talk about it
first. So, I think I am going to talk about it and see where it goes next year and then I will make my decision after that [post-NOS teaching beliefs interview].

The aforementioned two examples indicate that even though Anna did not change her ratings, she believed less in the developmental appropriateness and/or importance of teaching the bounded NOS aspect and the absence of a single step-by-step scientific method at the fifth grade level because she did not have positive feedbacks about student learning outcomes related to only these two NOS aspects.
Table 12
Anna’s Pre-NOS Training, Post-NOS Training (Post1), and Post-NOS Teaching (Post2) Ratings and Rankings for the Developmental Appropriateness and Importance of Teaching the Ideas about Science for her Fifth Graders

<table>
<thead>
<tr>
<th>Idea about science</th>
<th>Appropriateness</th>
<th>Importance</th>
<th>Teaching</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post1</td>
<td>Post2</td>
</tr>
<tr>
<td>Inferential NOS</td>
<td>5/1</td>
<td>5/3</td>
<td>5/-a</td>
</tr>
<tr>
<td>Creative NOS</td>
<td>4/8</td>
<td>4/7</td>
<td>5/-a</td>
</tr>
<tr>
<td>Tentative NOS</td>
<td>5/2</td>
<td>5/2</td>
<td>5/-a</td>
</tr>
<tr>
<td>Empirical NOS</td>
<td>4/9</td>
<td>5/1</td>
<td>5/-a</td>
</tr>
<tr>
<td>Subjective NOS</td>
<td>4/4</td>
<td>3/8</td>
<td>4/-a</td>
</tr>
<tr>
<td>Socio-cultural NOS</td>
<td>5/7</td>
<td>5/6</td>
<td>5/-a</td>
</tr>
<tr>
<td>Scientific Methods</td>
<td>5/3</td>
<td>4/4</td>
<td>4/-a</td>
</tr>
<tr>
<td>Collaborative NOS</td>
<td>4/6</td>
<td>4/5</td>
<td>5/-a</td>
</tr>
<tr>
<td>Bounded NOS</td>
<td>4/5</td>
<td>3/9</td>
<td>3/-a</td>
</tr>
</tbody>
</table>

Note. The first number in each cell shows the participant’s degree of agreement regarding the developmental appropriateness or importance of the idea from 1 (not at all appropriate/important) to 5 (very appropriate/important). The second number in each cell presents the participant’s rank for the developmental appropriateness or importance of the idea, ranging from 1 representing “the most appropriate/important idea about science” to 9 representing “the least appropriate/important idea about science”. aThe participant rejected to rank the NOS aspects because she did not consider any of the NOS aspects the most appropriate/important or the least appropriate/important. bThe participant changed her rating for the idea during the interview.
Nancy’s Post-NOS Teaching Beliefs

After the NOS teaching experience, Nancy further strengthened her beliefs that all of the NOS aspects were appropriate and important to teach at the fifth grade level by stating “different activities I did with my kids made me realize that with fifth graders these are all appropriate and important for them to learn. I don’t think that there’s any certain one that I would say that just doesn’t matter” [post-NOS teaching beliefs interview]. Consistent with her strengthened beliefs, Nancy gave the same ratings for all of the NOS aspects after her NOS teaching experience (See Table 13 for Nancy’s pre- and post-NOS teaching ratings of developmental appropriateness and importance).

Nancy considered all of the NOS aspects, even the bounded NOS aspect “very appropriate” and “very important” to teach at the fifth grade level at the end of her NOS teaching experience. Therefore, she highlighted during her interview that it was difficult for her to rank these nine NOS aspects in terms of their developmental appropriateness and importance. In this regard, Nancy was able to select only the most and the least appropriate/important NOS aspect after her NOS teaching experience. As seen in the Table 13, she continued to consider the inferential and creative NOS aspects among the most appropriate/ important ideas about science. However, this time Nancy based her rankings on the extent to which her fifth graders made reference to these NOS aspects during her NOS teaching. She observed that her students most of the time identified the inferential and creative NOS aspects in the NOS activities. Therefore, Nancy once again placed these two NOS aspects at the top of her list.

Similar to the top ideas about science, after her NOS teaching experience Nancy placed the same NOS aspects at the bottom of her list (See Table 13 for Nancy’s pre- and
post-NOS teaching rankings of the NOS aspects). She continued to believe that it was relatively less appropriate and important to teach the collaborative and bounded NOS aspect. During her post-NOS teaching interview, Nancy explained her reason for the placement of the collaborative and bounded NOS aspects as follows.

I think that there is not as much to explore like with those [the collaborative and bounded NOS aspects]. I think it is still like they can identify it and we can talk about how, you know, they are true and why science is influenced by those aspects, but I think that they are not always going to be like a super important like aspect of each and every thing. In fact, a lot of the activities that we do that like you wouldn’t even have number nine [the bounded NOS aspect] come up or eight [the collaborative NOS aspect]. Those don’t seem to really, you know, always – they’re not always relatable with what kind of things we’re doing [post-NOS teaching beliefs interview].

As seen in the above excerpt, Nancy again based her rankings on the number of references her fifth graders made for the NOS aspects during her NOS teaching. She placed the collaborative and bounded NOS aspects at the bottom of her list because she observed that her students less frequently identified these two NOS aspects. While determining the developmental appropriateness and importance of the bounded NOS aspect, Nancy also seemed to be influenced by the level of sophistication in her understanding of this particular NOS aspect because she stated “I think that is a little bit more nebulous for me as far as it is not quite as concrete, but I don’t think it is any less important, but it’s still just a little bit hazy for me” [post-NOS teaching beliefs interview].
Table 13

*Nancy’s Pre-NOS Training, Post-NOS Training (Post1), and Post-NOS Teaching (Post2) Ratings and Rankings for the Developmental Appropriateness and Importance of Teaching the Ideas about Science for her Fifth Graders*

<table>
<thead>
<tr>
<th>Idea about science</th>
<th>Appropriateness</th>
<th>Importance</th>
<th>Teaching</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post1</td>
<td>Post2</td>
</tr>
<tr>
<td>Inferential NOS</td>
<td>4/3</td>
<td>5/2</td>
<td>5/1(^b)</td>
</tr>
<tr>
<td>Creative NOS</td>
<td>5/7</td>
<td>5/3</td>
<td>5/1(^b)</td>
</tr>
<tr>
<td>Tentative NOS</td>
<td>5(^a)/8</td>
<td>5/5</td>
<td>5/1(^b)</td>
</tr>
<tr>
<td>Empirical NOS</td>
<td>5/2</td>
<td>5/1</td>
<td>5/1(^b)</td>
</tr>
<tr>
<td>Subjective NOS</td>
<td>5(^a)/5</td>
<td>5/4</td>
<td>5/1(^b)</td>
</tr>
<tr>
<td>Socio-cultural NOS</td>
<td>5/6</td>
<td>5/7</td>
<td>5/1(^b)</td>
</tr>
<tr>
<td>Scientific Methods</td>
<td>5/1</td>
<td>5/6</td>
<td>5/1(^b)</td>
</tr>
<tr>
<td>Collaborative NOS</td>
<td>5(^a)/9</td>
<td>5(^a)/8</td>
<td>5/9(^b)</td>
</tr>
<tr>
<td>Bounded NOS</td>
<td>4/4</td>
<td>3/9</td>
<td>5/9(^b)</td>
</tr>
</tbody>
</table>

*Note.* The first number in each cell shows the participant’s degree of agreement regarding the developmental appropriateness or importance of the idea from 1 (not at all appropriate/important) to 5 (very appropriate/important). The second number in each cell presents the participant’s rank for the developmental appropriateness or importance of the idea, ranging from 1 representing “the most appropriate/important idea about science” to 9 representing “the least appropriate/important idea about science”. \(^a\)The participant changed her rating for the idea during the interview. \(^b\)The participant rejected to rank all of the NOS aspects, but she considered the inferential and creative NOS aspects as the most appropriate and important ideas, while the collaborative and bounded NOS aspects as the least appropriate and important ideas about science to teach at the fifth grade level.
Andy’s Post-NOS Teaching Beliefs

After his NOS teaching experience, Andy did not show drastic quantitative changes in his beliefs about the developmental appropriateness and importance of teaching the NOS aspects at the fifth grade level because he gave the same ratings for almost all of the NOS aspects (See Table 14 for more information about Andy’s pre- and post-NOS teaching ratings of developmental appropriateness and importance for each NOS aspect). However, he seemed to reinforce his beliefs that all of the NOS aspects were appropriate and important to teach at the fifth grade level because he rejected to rank the nine NOS aspects at the end of his NOS teaching. In addition to his beliefs about teaching NOS in general, Andy seemed to strengthen his beliefs about the relative appropriateness and importance of the NOS aspects at the end of his NOS teaching because Andy put the NOS aspects into the categories of ‘very appropriate/ important’, ‘pretty appropriate/ important’ and ‘not very appropriate/ important’ at the end of his NOS teaching.

Among the nine NOS aspects, Andy changed his ratings only for the developmental appropriateness of creative NOS aspect and the importance of tentative and subjective NOS aspects. However, he did not consider these differences in his ratings as real changes in his beliefs. Rather, he claimed that they might have been resulted from his confusion about the terms of appropriateness and importance. This claim seemed to be supported when Andy’s pre- and post-NOS teaching explanations for the given ratings were taken into account. For instance, at the beginning of his NOS teaching, Andy rated the creative NOS aspect as “somewhat appropriate” because of his students’ having some misconceptions about the creative NOS aspect. At the same time, he considered teaching
the creative NOS aspect “very important” in order to clear these misconceptions. At the end of his NOS teaching, Andy continued to think that some of his students held misconceptions about the creative NOS aspect by stating that “I think that there are a lot of kids who just think science is just the thing you read, you know, you read it out the book and it tells this is what it is” [post-NOS teaching beliefs interview]. However, this time he rated the creative NOS aspect not only “very important” but also “very appropriate” to teach at the fifth grade level. In other words, Andy seemed to acknowledge that he should have rated the creative NOS aspect “somewhat appropriate” because he still thought that some of his students could not understand the role of creativity and imagination in science.

Even if Andy did not show significant quantitative changes in his ratings of developmental appropriateness and importance, he believed that the NOS teaching experience provided additional evidence for his pre-existing beliefs about certain NOS aspects. For instance, Andy already rated on his post-NOS training questionnaire that teaching the idea that science cannot answer questions related to religion, ethics, or philosophy was somewhat appropriate to teach at the fifth grade level because it was a higher-level concept for most of his students. During his post-NOS teaching interview, Andy stated “it showed me I was correct in the way I was thinking that this [the bounded NOS aspect] is a really tough concept for them to get” because he observed that even smart students understood this particular NOS aspect at the face value. Andy believed that students could understand that science cannot answer all questions, but only a few of them could explain why that is the case by providing examples of what kinds of questions science cannot answer. Therefore, after his NOS teaching experience, Andy continued to
rate the bounded NOS aspect “somewhat appropriate” to teach at the fifth grade level (See Table 14).

In addition to the bounded NOS aspect, Andy provided very consistent ratings for the empirical NOS aspect since the beginning of the study. He already believed that his students could easily understand the idea that science is based on the observations of the natural world because they had already been exposed to this idea in previous grades. During his post-NOS teaching interview, Andy explained this consistency in his ratings across different occasions with his level of background knowledge and experience. He thought that he had a lot of knowledge and experience of teaching high achieving fifth graders in order to determine to what extent they could understand, or benefit from learning, a given topic, in this case the empirical NOS aspect.

Andy also seemed to use his previous science teaching experience to support his post-NOS beliefs about the developmental appropriateness and importance of teaching the absence of a single step-by-step scientific method. He perceived that he did not have so many opportunities to observe his students’ learning of the absence of a single step-by-step scientific method during his NOS teaching because there were not so many NOS activities specifically designed to teach this particular NOS aspect. However, Andy expressed during his interview that in general students could understand the idea that there is more than one ways to do science. Moreover, he pointed out that he might think differently about the developmental appropriateness and/or importance of teaching the absence of a single step-by-step scientific method if he was able to focus more on this particular NOS aspect during his NOS teaching.
Table 14
Andy’s Pre-NOS Training, Post-NOS Training (Post1), and Post-NOS Teaching (Post2) Ratings and Rankings for the Developmental Appropriateness and Importance of Teaching the Ideas about Science for his Fifth Graders

<table>
<thead>
<tr>
<th>Idea about science</th>
<th>Appropriateness</th>
<th>Importance</th>
<th>Teaching</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post1</td>
<td>Post2</td>
</tr>
<tr>
<td>Inferential NOS</td>
<td>4/1</td>
<td>5/1</td>
<td>5/1</td>
</tr>
<tr>
<td>Creative NOS</td>
<td>4/6</td>
<td>4/4</td>
<td>5/2</td>
</tr>
<tr>
<td>Tentative NOS</td>
<td>5/3</td>
<td>5/3</td>
<td>5/2</td>
</tr>
<tr>
<td>Empirical NOS</td>
<td>5/2</td>
<td>5/2</td>
<td>5/1</td>
</tr>
<tr>
<td>Subjective NOS</td>
<td>3/7</td>
<td>4/5</td>
<td>4/2</td>
</tr>
<tr>
<td>Socio-cultural NOS</td>
<td>5/4</td>
<td>5/6</td>
<td>5/2</td>
</tr>
<tr>
<td>Scientific Methods</td>
<td>5/5</td>
<td>4/7</td>
<td>4/2</td>
</tr>
<tr>
<td>Collaborative NOS</td>
<td>5/9</td>
<td>5/8</td>
<td>5/1</td>
</tr>
</tbody>
</table>

Note. The first number in each cell shows the participant’s degree of agreement regarding the developmental appropriateness or importance of the idea from 1 (not at all appropriate/important) to 5 (very appropriate/important). The second number in each cell presents the participant’s rank for the developmental appropriateness or importance of the idea, ranging from 1 representing “the most appropriate/important idea about science” to 9 representing “the least appropriate/important idea about science”. aThe participant rejected to rank the nine NOS aspects on the 9-point scale. Rather, he rated the NOS aspects as “very appropriate/important” (=1), “pretty appropriate/important” (=2), or “not very appropriate/important (=3). bThe participant changed her rating for the idea during the interview.
Cross Case Analysis of Post-NOS Teaching Beliefs

The cross-case analysis revealed that teaching NOS did not help the participants to make significant quantitative changes in their beliefs about the developmental appropriateness and importance of the nine NOS aspects because their ratings for the NOS aspects either stayed the same or changed slightly after their NOS teaching (See Table 15 for each participant’s pre- and post-NOS teaching ratings for the NOS aspects).

I realized that the participants did not change their ratings for a certain NOS aspect when their classroom observations about this particular NOS aspect were aligned with their pre-existing beliefs. For instance, since the beginning of the professional development program Anna believed that it is neither appropriate not inappropriate and neither important nor unimportant to teach the idea that science cannot answer questions related to religion, philosophy, ethics, or art (See Table 15 for Anna’s post-NOS training ratings for the bounded NOS aspect). During her NOS teaching, Anna observed that her fifth graders made only a few references to this particular NOS aspect or they understood only certain parts of this idea. These expected negative feedbacks about her students’ learning of the bounded NOS aspect showed Anna that what she already believed about teaching this particular NOS aspect was correct. Therefore, after her NOS teaching Anna continued to believe that it is not very appropriate and important to teach the bounded NOS aspect at the fifth grade level. Like Anna, Andy also had similar classroom observations about his high achieving students’ learning outcomes related to the bounded NOS aspect. Therefore, after the NOS teaching experience Andy believed that teaching this particular NOS aspect was proven to be somewhat appropriate and somewhat
important at the fifth grade level (See Table 15 for Andy’s pre- and post-NOS teaching ratings for the bounded NOS aspect).

I also realized that the participants made slight changes in their ratings about the developmental appropriateness and/or importance of teaching a particular NOS aspect when their classroom observations and their pre-existing beliefs about this particular NOS aspect were not consistent with each other. For instance, before teaching NOS Francine believed that it was very appropriate to teach the absence of a single step-by-step scientific method because it was an easy concept to understand for third grade students. In contrary to her expectation, Francine observed that her students could not identify the absence of a single step-by-step scientific method in the activities she taught in her classrooms. This unexpected negative feedback made Francine to adjust her rating about the developmental appropriateness of teaching the absence of a single step-by-step scientific method. She started to rate this particular NOS aspect somewhat appropriate rather than very appropriate to teach at the third grade level (See Table 15 for Francine’s pre- and post-NOS teaching ratings for the idea about scientific methods). Anna, on the other hand, started to consider the subjective NOS aspect more appropriate and important to teach at the end of her NOS teaching because she observed that her students understood this particular NOS aspect more easily than she expected. This unexpected positive student learning outcomes related to the subjective NOS aspect led Anna to increase her ratings one point for this particular NOS aspect after her NOS teaching (See Table 15 for Anna’s pre- and post-NOS teaching ratings for the subjective NOS aspect).

The cross-case analysis also showed that the participants’ assessment about the developmental appropriateness and/or importance of a certain NOS aspect were
sometimes influenced by their post-NOS teaching understanding of this particular NOS aspect. For instance, after the NOS teaching experience Francine decreased her ratings only for the idea about the absence of a single step-by-step scientific method. Meanwhile, she underlined that among the nine NOS aspects she still did not fully understand the idea about the absence of a single step-by-step scientific method because she used to teach the presence of a single step-by-step scientific method in her classrooms. In contrary to Francine, after the NOS teaching Anna better understood the creative NOS aspect, and consistently, she increased her ratings for this NOS aspect.

Even though the participants did not show significant quantitative changes after teaching NOS in their classrooms, they showed some qualitative changes in their beliefs about teaching NOS in general. They further strengthened their beliefs that all of the NOS aspects are appropriate and important to teach at the elementary level. The NOS teaching experience helped them to see that all of the NOS aspects were working in practice to a certain extent. Therefore, they started to reject or had difficulty in ranking the developmental appropriateness and importance of some NOS aspects. In other words, after the NOS teaching experience the participants strongly believed that they should introduce all of the NOS aspects at the elementary level even if some students might not fully understand certain NOS aspects (e.g., the bounded NOS aspect) at this point.
### Table 15
The Participants’ Pre- and Post-NOS Teaching Ratings for the Developmental Appropriateness and Importance of Teaching the Nine Ideas about Science

<table>
<thead>
<tr>
<th>Idea about science</th>
<th>Francine</th>
<th>Anna</th>
<th>Nancy</th>
<th>Andy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PreA(^{a})</td>
<td>PostA(^{b})</td>
<td>PreI(^{c})</td>
<td>PostI(^{d})</td>
</tr>
<tr>
<td>Inferential</td>
<td>5/M</td>
<td>5/T(^{e})</td>
<td>5/T(^{e})</td>
<td>5/T(^{e})</td>
</tr>
<tr>
<td>Creative</td>
<td>5/T</td>
<td>5/T(^{e})</td>
<td>5/T(^{e})</td>
<td>5/T(^{e})</td>
</tr>
<tr>
<td>Tentative</td>
<td>5/T</td>
<td>5/T(^{e})</td>
<td>5/T(^{e})</td>
<td>5/T(^{e})</td>
</tr>
<tr>
<td>Empirical</td>
<td>5/M</td>
<td>5/M</td>
<td>5/M</td>
<td>5/T</td>
</tr>
<tr>
<td>Subjective</td>
<td>5/T</td>
<td>5/M</td>
<td>5/M</td>
<td>5/M</td>
</tr>
<tr>
<td>Socio-cultural</td>
<td>5/M</td>
<td>5/B</td>
<td>5/B</td>
<td>5/M</td>
</tr>
<tr>
<td>Scientific Methods</td>
<td>5/B</td>
<td>4/B</td>
<td>5/B</td>
<td>4/B</td>
</tr>
<tr>
<td>Collaborative</td>
<td>5/B</td>
<td>5/M</td>
<td>5/M</td>
<td>5/M</td>
</tr>
</tbody>
</table>

Note. \(^{a}\)“PreA” means the participant’s rating or ranking about the developmental appropriateness of the idea before teaching NOS. \(^{b}\)“PostA” means the participant’s rating or ranking about the developmental appropriateness of the idea after teaching NOS. \(^{c}\)“PreI” means the participant’s rating or ranking about the importance of the idea before teaching NOS. \(^{d}\)“PostI” means the participant’s rating or ranking about the importance of the idea after teaching NOS. In the appropriateness and importance columns, the number present the participant’s degree of agreement regarding each idea about science from 1 (not at all appropriate/important) to 5 (very appropriate/important), while the letter presents the participant’s placement of the idea at the bottom (B), middle (M), or top (T) of his or her list when s/he compared the nine ideas about science in terms of their developmental appropriateness or importance. \(^{e}\)The participant rejected or had difficulty in ranking the developmental appropriateness and importance of the NOS aspect. \(^{f}\)The participant changed the rating for the corresponding idea during the interview.
Research Question Three

The third research question investigated which components of the professional development program the participants perceived contributed, or might have contributed, to their conceptions of the NOS aspects and their beliefs about the developmental appropriateness and importance of teaching the NOS aspects at their grade level. The data obtained from the participants’ post-NOS training and post-NOS teaching interviews, the field notes, and classroom observations were examined to identify the elements of the professional development program that played a significant role in changing the conceptions of NOS and beliefs about the developmental appropriateness and importance of the NOS aspects. This cross-case analysis resulted in nine components increasing the effectiveness of the professional development program on NOS.

Specific Focus on the NOS Content

All of the participants highlighted that they did not receive any instruction that specifically address what science is and how science works in their teacher education programs and in the professional development programs that they participated in previous years. Therefore, they found the specific focus on the NOS content in this professional developmental program very helpful for their understanding of NOS. For instance, Francine expressed the importance of explicit NOS instruction in improving her understanding of NOS as follows: “I still not, you know, fully understand this subject [NOS], but I think I am in a right track and getting there. So, even like the two months, three months training affects and changes everything” [post-NOS training interview]. Anna also expressed the need for targeting different NOS aspects in order to develop a general understanding of science: “Actually understanding all the components of nature
of science, the different parts of nature of science, which I was never exposed to prior to this helped me formulate the bigger picture, not just zoom in smaller things” [post-NOS training interview]. In addition to the need for explicit NOS instruction for developing more accurate understanding of science in general, Nancy pointed out how targeting different NOS aspects clarified her understanding of the tentative NOS aspect in specific. Andy believed that being exposed to different aspects of NOS also helped him articulate his NOS conceptions by using a more appropriate language.

In addition to their conceptions of NOS, the participants perceived that being exposed to the nine NOS aspects during the NOS training contributed to their beliefs about the developmental appropriateness and importance of teaching NOS. For instance, Andy expressed the influence of targeting the nine NOS aspects as learning outcomes of the professional development program on his beliefs about the importance of teaching the bounded NOS aspect as follows:

I was now seeing that this [the bounded NOS aspect] is one of those nine things on the list. It’s definitely something that they [students] should be at least exposed to. Even if they don’t completely understand it, at least maybe they’ve heard it and they can then, you know, put it together later…So it’s important even if they’re not going to totally get it, that at least the idea is being planted where you can hear a statement, but not necessarily totally grasp and understand it and how it is applied, but at least maybe you’re putting that – the seed of something there for them to understand in the future. So even if they’re not totally getting it, you know, we’ll give them a shot, you know [post-NOS training beliefs interview].
The above excerpt indicates that Andy was convinced about the importance of teaching the bounded NOS aspect because it was one of the NOS aspects targeted in the NOS training. In other words, Andy perceived that if the bounded NOS aspect was not an important characteristic of science to be taught, they would not be exposed to this idea about science during the NOS training.

**Participation in Hands-on NOS Activities**

All of the participants mentioned that doing hands-on activities on NOS (e.g., the *Bottle* activity, the *Cube* and *Fossils* activities [Lederman & Abd-El-Khalick, 1998], and *Tangram* activity [Choi, 2004]) helped not only them but also their students to develop more sophisticated NOS conceptions. For instance, Andrew explained the use of history of science and hands-on NOS activities in his students’ learning of the tentative NOS aspect as follows.

> Before we were learning in class, you know, let’s say about Galileo and oh, well people used to think this and I hear that they think of this is something, oh that was like a really long time ago and it was like a long process to get to that point because oh, well, people didn’t accept his ideas at first and they told him, oh, you’re wrong and we’re sticking with our belief. So, I think that by doing that, sometimes they feel that this is a very long and drawn out process whereas some of the activities we did – if it was the mice or the bottle or anything where they’re trying to figure out what’s going on, they all of a sudden see your theory can change within a few minutes of what you’re thinking is going on. So, I think that it’s nice because it kind of compressed that span of time for them down into something that was more tangible [post-NOS teaching interview].
The above excerpt indicates that Andy found the hands-on NOS activities more effective than history of science examples for teaching the tentative NOS aspect because he perceived that hands-on activities provided more concrete learning experience for his students.

**Educational Readings on NOS**

During the NOS training, the participants read and discussed two articles on NOS: (1) McComas’ (1998) article on 15 myths about NOS that are commonly included in science textbooks, in classroom discourse, and in the minds of students and teachers and (2) Akerson and her colleagues’ (Akerson, Weiland, Pongsanon, & Nargund, 2010) article on a research-based model for teaching NOS and strategies to teach NOS to young children. During the interviews, three of the participants (Francine, Anna, and Andy) talked about the influence of reading the NOS myths on their understanding of NOS. For instance, after the NOS training Andrew no longer used the terms “prove” and “disprove” to articulate his NOS conceptions. During his post-NOS training interview, he expressed that this change in his language might be resulted from reading McComas’ (1998) article. Andrew thought that reading the myths about NOS at the beginning of the professional development program triggered his understanding that you cannot prove or disprove something in science. In other words, Andrew perceived reading McComas’ (1998) article on NOS myths as a good starting point to refine his NOS conceptions. Francine also thought that reading the myth article had some contributions to her NOS conceptions. She expressed during her post-NOS training interview that reading the article was one of the influential factors for her realization that experiments are not the principal route to scientific knowledge. As seen in the following excerpt, Anna also
thought that the reading of the myth article coupled with other components of the professional development program helped her to seek alternative views that are more consistent with contemporary conceptions of NOS.

The researcher: So, what do you think helped you to change your idea? What is much more responsible for the change you expressed about the definition of experiment?

Anna: I think it was actually one of the papers that we read. Sometimes you don’t think of things in a certain way, you know. You so used to presenting especially to kids and that is just like your frame of mind that time. You really think of them until somebody brings up you and says. Wait a minute! Can’t you think this way or that way and then you are like oh, you can. So, I guess the group discussion and the articles helped me really think about what we are doing [post-NOS training interview].

Here and also in other contexts Anna underlined that educational reading was important, but not sufficient for one to develop an appropriate understanding of NOS. She thought that an effective professional development program on NOS should have a nice mixture of educational readings, activities, and discussions.

**Multiple Types/ Formats of Reflection**

All of the participants perceived that the NOS training activities (e.g., hands-on activities, educational readings, analyzing student data, and examining the national and state science standards) contributed to their learning of NOS when they were coupled with multiple types/ formats of reflection (i.e., written or oral reflection, structured or unstructured reflection, and individual or group reflection). They all thought that
discussions with colleagues provided them a safe space to grapple the range of thoughts that aroused from the learning experience as seen in the below excerpt.

Anna: I think it is an accumulation of a lot of things, with solving the activities, reading the articles, and having the discussions. I mean the discussion helped when you set a small group, and you and somebody talks about an idea. You feed of what other people is saying. They really started to make the things so. The articles provide you with the information; the group discussion helps you to kind of foster the way you think about it. When you are having a dialogue with somebody discussing an educational topic and then you pick up the parts that you agree with and can argue with the parts that you don’t and which I think forms the ideas in your head... So, it was nice to be able to have an article and then doing an activity and then have a discussion instead of like completely focusing on reading all articles or just doing activity, after activity after activity instead of breaking up into little things in between [post-NOS training interview].

In addition to discussions with peers, all of the participants thought that their understandings of NOS were enhanced when they completed the structured worksheets that link the learning experience with the NOS framework. For instance, Francine explained how the structured worksheets and discussions with colleagues contributed to her learning of NOS as follows.

Francine: after every activity we were talking like [Nancy] had one sentence, [Andy] had five, [Anna] has three or something. When we combine everything,
this could be too, this could be too. So, I like listening others’ ideas and I always
learn from others. That might be, discussing together, yes.

The researcher: Can I say discussion after each activity?

Francine: because each time you are giving us a paper that we were filling out and
then after we compare our answers it helped me to understand better, like each
discussion. Discussion helped me with this.

The researcher: Do you mean we did the activity, but if we did not do reflection
or discussion after the activity, it will not help you?

Francine: it might, but not really because we were going to do the activity and
move on, activity and move on, but each reflection and each discussion helped me
better, I can say [post-NOS training interview].

As seen in the above excerpt, Francine thought that structured self-reflection followed by
group-reflection enhanced her understanding of NOS because she was able to exchange
relevant information with her colleagues. Francine also mentioned that the probing
interview questions on her written questionnaire responses provided an opportunity for
her to reflect on and then clarify her NOS conceptions. In other words, Francine
considered the data collection sources as a means for reflection on her NOS conceptions.

All of the participants considered reflection through completing structured
worksheets very important not only for them but also their students’ learning of NOS.
They thought that such structured worksheets direct the learner’s attention to important
issues/questions and connect the experience to the NOS content. Therefore, during their
NOS teaching the participants either used the worksheets that I prepared to be used in the
NOS training or developed their own worksheets to provide prompts to guide the
reflective process. For instance, Anna developed a fill-in-the-blank worksheet to prompt her fifth graders’ reflection on the videos that address different aspects of NOS. After Anna, Francine and Nancy used the videos and worksheet to introduce the NOS aspects in their classrooms because they all believed in the necessity of such structured worksheets in the learning of students, especially at elementary grade levels.

**Multiple Exposure to the NOS Content**

All of the participants thought that their understandings of NOS were enhanced when they saw multiple applications of the NOS aspects across a variety of NOS activities. During his post-NOS training interview, Andy explained the importance of the repetition across different contexts in clarifying a learner’s understanding of NOS as follows.

Well, I think just, you know, as you’re looking at the things on the poster [the NOS poster] and on the list [the NOS aspects definitions list] and as you talk about them and see them in different situations over and over and over again, you start to go, oh, okay… You have to like refresh and review for yourself over and over again, and the more you see the different applications in different situations and you know, where you kind of see it in one activity, and then you see the same idea apply it in a slightly different way in a different activity, it starts to really solidify that. So, I think that’s, you know, a key element to this is that. We didn’t just go down the list and say, okay, activity one we’re going to learn about, you know, the limited – the bounded [NOS aspect] or whatever and then the next activity, okay, we’re going to learn about empirical [NOS aspect], and then the next activity we’re going to learn about this. Because if you did all that,
technically you would have covered everything, but I don’t think you would’ve gotten as robust or deep knowledge of each individual one of those things [post-NOS training interview].

As seen in the above excerpt, Andy, and similarly other participants, considered the NOS poster or the list on the definitions of the NOS aspects as a helpful tool to make references to the NOS aspects across different contexts. Moreover, they perceived that the more they made a reference to a particular NOS aspect across different contexts, the more they understood this particular NOS aspect.

The participants also changed their beliefs about the developmental appropriateness and importance of teaching NOS aspects after realizing the importance of seeing the NOS aspects in different contexts for their learning of NOS. While reflecting on the NOS activities at the beginning of the NOS training, all of the participants highlighted that they would just focus two or three NOS aspects in each NOS activity. They believed that it is not very appropriate to address more than two or three NOS aspects at a time because it would confuse their elementary students. However, after the NOS training the participants started to express that teaching more than two or three NOS aspects would not be a problem for their elementary students. They were convinced that students should be provided multiple opportunities to apply the NOS aspects to have a better understanding of NOS. The following excerpt illustrates this point.

Andy: because you’re seeing it multiple, multiple, multiple times, and that’s one of the reasons why when we’re talking about how we’re planning on introducing these different elements to these children, I don’t see a problem with telling them, okay, all of these exist. We’re going to talk about a few of them today. You may
see them come up in other activities that you didn’t think were even meant for this. You might see one of these things pop up and say, oh, that’s sort of like this nature of science element, and I think that that’s the way you learn it. It’s not like okay, once I learned it, okay, now I have it [post-NOS training interview].

In addition to the change in their beliefs about teaching NOS in general, the participants sometimes made changes in their beliefs about teaching a certain NOS aspect. They considered a particular NOS aspect more appropriate or important to teach if they were able to make a reference to this particular NOS aspect across different contexts during the NOS training. For instance, Francine moved up the creative NOS aspect from the bottom to the top of her lists when she compared the developmental appropriateness and importance of the nine NOS aspects (See Table 6) because she observed that the creative NOS aspect was more frequently identified in the NOS training activities. In other words, Francine’s decisions about the developmental appropriateness and importance of teaching the creative NOS aspect were influenced by the frequency of the references she or her peers made to this particular NOS aspect across different NOS activities.

**Structural Consistency**

During the NOS training, the participants followed the same structure: They first did the NOS training activities such as educational readings on NOS and hands-on NOS activities and then they reflected on the learning experience by making references to the NOS aspects presented on the poster or in the list. During their post-NOS training interviews or our informal talks after these interviews, they all highlighted that this structural consistency in the NOS training significantly contributed to their learning of
NOS. After following the same structure many times, the participants came to realize that whatever they did in the activities would be connected to the poster or list. In other words, the structural consistency promoted the participants to connect experiences to the key points discussed during the NOS training. During his post-NOS training interview, Andy explained the coherence in the NOS training as follows: “because you are constantly referring back to [the poster or the list], oh, yeah, now it just makes sense that this is the thing that is tying everything together. So, hey, what we are doing always relates back to this paper or the poster” [post-NOS training interview].

**The Evaluation of Secondary Student Data**

One of the NOS training activities gave the participants an opportunity to assess elementary students’ NOS conceptions. Teachers were provided with data from previously published studies about NOS and they were asked to evaluate elementary students’ ideas about particular NOS aspects and to classify students’ NOS ideas as inadequate, adequate, or informed. Two of the four participants found this evaluation of secondary student data influential in their learning of NOS. During their interviews, Francine and Nancy expressed that sorting a range of ideas on a particular NOS aspect based on their level of sophistication forced them to clarify and reinforce their own NOS conceptions. For instance, Nancy thought that she started to give specific examples illustrating her NOS conceptions after assessing students’ NOS ideas as inadequate, adequate, or informed because she realized during this NOS training activity that the students’ NOS ideas were considered as being informed when they gave examples as a part of their answers.
The Analysis of National and State Science Standards in terms of NOS

One of the NOS training activities required the participants to examine and compare the NOS contents in the three national science education policy documents (i.e., the Benchmarks for Science Literacy [AAAS, 1993], NSES [NRC, 1996], and NGSS [NGSS Lead States, 2013]) and the science education standards in the state. This experience seemed to have some contributions to the participants’ beliefs about the importance of teaching NOS. For instance, at the beginning of the NOS training Andy made his decision about the importance of teaching the subjective NOS aspect based on his perceptions about the difficulty of this idea and the absence of this idea in the standards by stating “harder to understand, not as necessary for standards” [pre-NOS training beliefs questionnaire]. After completing the analysis of the policy documents and state science standards in terms of NOS, Andy pointed out that the consistency of the NOS contents across different standards documents highlights the importance of teaching NOS in general. Interestingly, at the end of the NOS training Andy increased his rating from “somewhat important” to “very important” for the subjective NOS aspect and he no longer mentioned the absence of the subjective NOS aspect in the standards. Similar to Andy, after completing the analysis of the policy documents and state science standards Anna also seemed to acknowledge the importance of teaching NOS in general by stating “I did not think nature of science is embedded into standards that much before” [the NOS training field notes]. In other words, the increased awareness of the consistent integration of the NOS contents in the major science education policy documents over the years seemed to help the teachers appreciate the importance of teaching NOS.
The Implementation of the NOS Activities in the Classroom

The professional development program provided during the course of this study consisted of two phases. In the first phase, the participants received training on NOS. In the second phase, they implemented some of the activities that were used in the NOS training in their classrooms. During their post-NOS teaching interviews, all of the participants perceived that the implementation of the NOS activities in their classroom contributed to their conceptions of NOS. As seen in the following excerpt, Francine thought that her NOS conceptions about the tentative NOS aspect became fruitful after implementing the NOS activities in her classroom.

First you don’t know anything about something and you get training or you start believing in a something, but you are not really sure exactly how this is going to work. When you teach, you see it is really working. So, of course it helped me, but I cannot really say that in specific way or in a specific example or this specific activity helped me to understand this [the tentative NOS aspect] [post-NOS teaching interview].

In addition to strengthening her NOS conceptions, Francine also acknowledged that the NOS teaching experience enhanced her NOS conceptions by stating “when you try to come up with an explanation to the kids, like this is an opinion and this is scientific knowledge, you dig more what is opinion and what is scientific knowledge. When you dig more, you learn more [post-NOS teaching interview]. Francine also talked about how her understanding of certain NOS aspects became clarified after implementing the NOS activities in her classrooms. For instance, she observed during her NOS teaching experience that her students always made a reference to the creative NOS aspect without
paying the required attention to the empirical NOS aspect. This classroom observation forced Anna to make the distinction between science and art in her mind. She thought that it became obvious both science and art need creativity and imagination, but science is linked to empirical evidence. In other words, Anna had to decipher her creative NOS conceptions after implementing the NOS activities in her classrooms.

In addition to NOS conceptions, all of the participants thought that the implementation of the NOS activities in their classrooms had some contributions to their beliefs about the developmental appropriateness and importance of teaching NOS. They thought that the NOS teaching experience provided an opportunity to test their beliefs in real classroom settings. During their NOS teaching experience, the participants collected evidence about their students’ learning outcomes to make a decision about to what extent a particular NOS aspect is appropriate and important to teach. For instance, after her NOS teaching experience Anna started to consider the subjective NOS aspect more appropriate and important to teach at the fifth grade level because she observed that her students understood this particular NOS aspect more easily than she expected. Francine, on the other hand, strengthened her beliefs that it is not very appropriate to teach the absence of a single step-by-step scientific method because she felt that her students did not really understand this particular NOS aspect.
Chapter 5 Discussions and Implications

Introduction

This chapter is divided into four main sections. The first section, the study overview, includes the review of the research questions guiding the study and the summary of procedures followed in the study. Section two discusses the significance of the major findings for each of the research questions. Section three presents the implications of the research findings for teachers and researchers in the fields of science education and teacher education, and section four discusses the limitations of the study.

Study Overview

The present qualitative study investigated the impact of an academic-year long, professional development program on the elementary teachers’ conceptions of the target NOS aspects and their beliefs about the developmental appropriateness and importance of teaching these NOS aspects. Moreover, it explored the participating teachers’ perceptions about which components of the professional development program contributed to their conceptions of the target NOS aspects and their beliefs about the developmental appropriateness and importance of teaching the target NOS aspects.

The professional development program was conducted in a high achieving state funded tuition free public charter school in the southwest region of the United States. It consisted of two main phases. In the first phase, the participants received training on NOS. In the second phase, they taught several NOS lessons in their classrooms. Out of 8 third through fifth grade science teachers, four of them completed both the first and second phases of the study. Thus, a total of 4 elementary science teachers consisted of the participants of this study. Qualitative data in this study were collected from multiple
sources at the beginning of the professional development, after the NOS training, and after the NOS teaching. Accordingly, the present study examined the changes in elementary science teachers’ conceptions of the target NOS aspects and their beliefs about the developmental appropriateness and importance of teaching the target NOS aspects as well as the perceived reasons facilitating these changes after the NOS training and the NOS teaching by using pattern matching, explanation building, and cross-case synthesis (Yin, 1994, 2003).

**Research Question One**

The first research question investigated in the present case study was concerning the influence of the professional development program on the participating elementary teachers’ conceptions of the target NOS aspects. The analyses of individual and cross-cases revealed that the participants showed gradual, but noteworthy changes in their conceptions of the target NOS aspects over the course of one academic-year long, professional development program. They refined their NOS conceptions by giving many examples and making connections across different aspects of NOS not only after their participation in explicit-reflective NOS instruction but also after teaching NOS in their classrooms. In this regard, these findings provide additional empirical evidence about the effectiveness of explicit-reflective NOS instruction on improving teachers’ NOS conceptions (e.g., Abd-El-Khalick, 2001; Abd-El-Khalick & Akerson, 2004; Akerson & Abd-El-Khalick, 2003; Akerson et al., 2000; Akerson, et al., 2007; Celik & Bayrakceken, 2012; Dass, 2005; Koening et al., 2012). Moreover, the findings provide further insights about teachers’ learning of NOS by documenting positive changes in teachers’ NOS conceptions after their NOS teaching in their classrooms. Previously, researchers have
shifted their attention from investigating the changes in teachers’ NOS conceptions to investigating the relationship between teachers’ NOS conceptions and their classroom practice or students’ learning of NOS (Lederman, 1992, 2007). However, the influence of NOS teaching on teachers’ NOS conceptions has remained unexplored. The present study suggests that the act of teaching NOS could also help teachers improve their NOS conceptions because teaching NOS allows them to further reflect on their own NOS conceptions. In addition, teaching NOS provides a context for teachers to test the applicability of newly acquired conceptions with their students. From the conceptual change perspective, NOS teaching helped teachers to find their NOS conceptions more fruitful (Posner et al., 1982).

Even though the participants showed positive changes in their NOS conceptions after their participation in the professional development program, these changes generally were not revolutionary in nature. They continued to think that science is empirical, creative, tentative, and subjective both after their participation in explicit-reflective NOS instruction and after their implementation of several NOS training activities in their classrooms. From the conceptual change framework of learning outlined by Vosniadou (1994), these findings imply that the participants in this study achieved enrichment type of conceptual change for the empirical, creative, tentative, and subjective NOS aspects rather than revision type of conceptual change. They gradually modified their mental models on these four NOS aspects through adding information to their existing conceptual structures.

The slight changes that the study participants showed in their conceptions of the empirical, creative, tentative, and subjective NOS aspects after a yearlong professional
development program on NOS could be explained in two ways. First, the participants’ prior knowledge about NOS might have mediated their learning of NOS during the professional development program. Since the study participants already started the professional development program with somewhat informed conceptions of certain NOS concepts, they might not have perceived a need to change their pre-existing conceptions of these particular NOS aspects. Therefore, they might not have changed their conceptions of these particular NOS aspects drastically. This relationship between the learner’s prior knowledge and learning was consistent with the findings of previous empirical studies that investigated teachers’ learning of NOS (e.g., Akerson et al., 2009a; McDonald, 2010). In addition to the empirical studies on NOS, the activation of prior knowledge in the process of learning was also acknowledged in the theories of conceptual change (e.g., Pintrich et al., 1993; Posner et al., 1982; Strike & Posner, 1992). Second, the participants’ beliefs about the developmental appropriateness and importance of teaching NOS sometimes might have regulated their learning of NOS. For instance, Anna felt change in her conceptions of the creative NOS aspect only after she realized the need for addressing the difference between creativity in science and creativity in art in her classroom. Before her NOS teaching, Anna believed that it is not very important to teach the creative NOS aspect because she thought that students at this age are naturally creative. The change that Anna perceived in her conceptions, and beliefs about the importance, of the creative NOS aspect was also visible when her explanations given for this particular NOS aspect were compared across the three data collection points. Unlike pre- and post-NOS training, Anna was able to differentiate scientific and artistic creativity by appealing to the empirical NOS aspect after teaching NOS in her classroom.
These findings seemed to be consistent with previous studies (McDonald, 2010; Schwartz & Lederman, 2002) that identified the learner’s appreciation of the importance and utility value of NOS as mediating factors in learning about NOS. Similarly, Pintrich et al. (1993) included motivational factors, including the utility value and importance to describe the process of conceptual change. They argued in their hot conceptual change model that the students’ motivational beliefs about themselves as learners and the individuals in the learning environment might influence (or sometimes determine) whether change occurs. In other words, some teachers in the present study might have shown less cognitive engagement in doing NOS tasks because of the lack of motivational beliefs about these tasks.

For the absence of a single step-by-step scientific method, one of the participants showed a revision type of conceptual change defined by Vosniadou (1994). After the NOS training Francine came to realize that there is no single step-by-step scientific method. However, she did not want to give up using “the scientific method” in her science teaching. Her pedagogical concerns about not using “the scientific method” were also shared by other participants. All of the participating elementary teachers thought that “the scientific method” provides them a useful heuristic for science teaching and/or science fair projects. They highlighted that introducing the idea that there is no step-by-step scientific method would propagate another student misconception that anything goes in science (Feyerabend, 1975). Therefore, the elementary teachers preferred teaching the scientific method first and then revise it with a more contemporary understanding that there is more than one way to do science. These findings suggest that misconceptions are often firmly held and difficult to extinguish even given instruction designed to alter those
ideas (Akerson et al., 2009a; Carey, 2000; McDonald, 2010; Treagust & Duit, 2009; Vosniadou, 1999).

**Research Question Two**

The second research question investigated in this case study was about the influence of the professional development program on the participating elementary science teachers’ beliefs about the developmental appropriateness and importance of teaching the target NOS aspects. The individual and cross-case analyses revealed that the participants started the professional development program with seemingly positive beliefs about teaching the NOS aspects. They thought that it is appropriate and important to teach all of the NOS aspects, yet they sometimes gave ratings or rankings for certain NOS aspects that were inconsistent with their beliefs about the developmental appropriateness and importance of those particular NOS aspects. These findings indicate that at the start of the professional development program the elementary teachers might not have internalized the appropriateness and importance of teaching the NOS aspects at the elementary grade levels. In this regard, the study findings show consistencies with previous studies (Bell et al., 2000; Kahana & Tal, 2014), in which teachers verbalized teaching NOS important, yet they did not always integrate NOS into their instruction.

The seemingly high motivational status of the elementary teachers at the start of this study could be explained by contextual variables. The study participants might have deemed teaching NOS important and appropriate because science in general was given a high priority at the school in which the teachers were working. The administrators at this high achieving school require their science teachers’ participation in science competitions such as Science Fair competition in the state. In other words, the school context might
have shaped the teachers’ motivational beliefs about teaching NOS (i.e., their beliefs about the developmental appropriateness and importance of teaching the nine NOS aspects). The present study was not the only study highlighting the interplay between teacher beliefs and context (Mansour, 2009; Nespor, 1985, 1987; Pajares, 1992; Windschitl & Sahl, 2002).

The participants’ feeling of a need to learn or teach about NOS could be another explanation for the status of the teachers’ motivational beliefs about teaching NOS. For instance, at the start of the study Anna and Andy explained their reasons for participating in the professional development program with their students’ poor achievement on NOS in high stakes exams. They voiced that in the exams their students were good at answering questions about traditional science contents (e.g., the functions of organs), yet they were bad at answering questions about NOS (e.g., acknowledgement of many societies’ and culture’s contributions to science). These two fifth grade teachers in this study, unlike the K-8 teachers in the study of Posnanski (2010), perceived NOS as a part of high stakes exams, and thus, they valued teaching NOS in their classrooms and showed commitment to participate in this professional development program on NOS. Nancy, on the other hand, felt a need to participate in the professional development program because she was new in teaching science at the time of the study. Francine was another elementary teacher who remained in the professional development program until its conclusion because she believed that she needed such explicit instruction on NOS because of the absence of this content in her teacher education program. These findings suggest the importance of need analysis for improving the effectiveness of inservice teacher education (Moeini, 2008) because the elementary teachers in this study is
expected to commit a significant amount of their time to the professional development program without any compensation (a stipend or a certification) unlike previous studies (e.g., Akerson et al., 2009a; Akerson et al., 2007; Posnanski, 2010).

Although the elementary teachers already verbalized that teaching NOS is important and appropriate, they internalized their beliefs as a result of their participation in the professional development program. The participating teachers made more informed decisions about the developmental appropriateness and importance of teaching NOS at the elementary grade levels because they perceived that they knew more about NOS and they witnessed the applicability of NOS in their classrooms. In other words, having overall positive feedbacks about the NOS learning of themselves and their students helped the participating teachers to reinforce their beliefs about the developmental appropriateness and importance of teaching NOS at the elementary grade levels. In this respect, the study findings were in line with Guskey’s (1985, 1986, 2002) model of teacher change. Guskey asserted that a professional development program would bring about a change in teachers’ beliefs only after teachers had tangible evidence of student success. For instance, teachers’ beliefs about the desirability of a particular curriculum or instructional innovation would change when the teachers saw the implementation of the new innovation helped their students attain higher levels of achievement or become more involved in instruction. As applied to the present study, the participants strengthened their beliefs about the developmental appropriateness and importance of teaching NOS because they saw first for themselves and then for their students that they were capable of understanding NOS and they benefited from learning about NOS. These findings suggest that the act of teaching is an integral part of inservice teacher education.
Another significant finding concerning the second research question in this study was that the participants showed resistance to change their beliefs of developmental appropriateness and importance for certain NOS aspects. The elementary teachers sustained the belief that it is not very appropriate and important to teach the idea that science cannot answer questions related to religion or ethics. They all thought that the elementary students could or should understand science cannot answer all questions, yet it was somewhat inappropriate and unimportant for them to understand what types of questions science cannot answer. The stability of teachers’ relatively negative beliefs about teaching the bounded NOS aspect throughout the professional development program seemingly supports the exclusion of this particular NOS aspect in previous studies with elementary teachers (e.g., Abd-El-Khalick & Akerson, 2004; Akerson & Abd-El-Khalick, 2003; Akerson et al., 2009a; Akerson et al., 2009b; Bell et al., 2011; Matkins et al., 2002; McDonald, 2010; Posnanski, 2010). However, the participating teachers, unlike these researchers, believed that the bounded NOS aspects should at least be introduced at the fifth grade in order to form a foundation for a full understanding of this particular NOS aspect at higher grade levels. In this respect, the study participants were in line with the policy makers in science education. According to the most recent science education standards, NGSS (NGSS Lead States, 2013), students of all ages are expected to learn the idea that \textit{science addresses questions about the natural and material world} with increasing sophistication. For instance, students in kindergartens to second grades could or should understand the NOS idea that \textit{scientists study the natural and material world}, while high school students could or should deepen this NOS understanding by acknowledging science does not provide answers or solutions to ethical
issues. In other words, the study participants suggest a learning progression for teaching the bounded NOS aspect as in the NGSS.

The participating teachers also showed resistance to change their beliefs about teaching the absence of a single step-by-step scientific method. All of the four teachers pointed out that they understood the absence of a single step-by-step scientific method; however, they retained to think based on their previous science teaching experience that teaching “the step-by-step scientific method” is necessary for elementary students to show better performance in science (i.e., the science fair projects). Therefore, the elementary teachers expressed that they would continue to teach this step-by-step scientific method, but they would also ensure to expose their students to the idea that these steps are not rigid. These findings suggest that teachers’ having appropriate NOS knowledge is necessary, but not sufficient for changing their beliefs about teaching NOS and their subsequent classroom practices. In this respect, this study provides additional empirical evidence for Lederman’s (2007) conclusion derived from his review of 50 years of NOS research that teachers do not automatically and necessarily translate their NOS conceptions into classroom practice. Moreover, it furthers this conclusion by highlighting the possible role of teachers’ motivational beliefs (i.e., their beliefs about the developmental appropriateness and importance of teaching the NOS aspects) in their classroom practice.

The participants’ robust beliefs about teaching the step-by-step scientific method despite of their improved NOS knowledge could be explain by research on beliefs. For instance, Rokeach (1968) claimed that all beliefs subsume three components: (a) a cognitive component (knowledge), (b) an affective component (judgment, evaluation, and
emotions), and (c) a behavioral component when action is necessary. In this study, the
elementary teachers knew that there is no single step-by-step scientific method (the
cognitive component), but they felt that teaching this idea is somewhat appropriate and
important at the elementary grade levels (the affective component) and they planned to
teach first the step-by-step scientific method and then revise it with the contemporary
understanding of the presence of multiple scientific methods (the behavioral component).
In other words, in contrary to the cognitive component, the affective and behavioral
components of the participating teachers’ beliefs about teaching the absence of a single
step-by-step scientific method were not fully refined with the professional development
program employed in this study.

**Research Question Three**

The third research question in this study investigated which components of the
professional development program the participating elementary teachers perceived
effective in changing their NOS conceptions and beliefs about the developmental
appropriateness and importance of teaching the NOS aspects. The individual and cross-
case analyses revealed nine components contributing to the effectiveness of the
professional development program: (a) specific focus on the NOS content, (b)
participation in hands-on activities on NOS, (c) educational readings on NOS (i.e.,
reading the article discussing the myths about NOS), (d) structured written and oral
reflection on the professional development activities as individual learners and as a group
of peers, (e) multiple exposure to the NOS content via a variety of activities, (f) structural
consistency in the presentation of the NOS content (first, reading or doing a hands-on
activity on NOS and then reflecting on the learning experience from the perspective of
the NOS aspects with the help of visual aids), (g) the evaluation of secondary student
data, (h) the analysis of national and state science standards in terms of NOS, and (i) the
implementation of the NOS activities in the classroom. The significance of these findings
is discussed in the following paragraphs in terms of both research on the characteristics of
an effective professional development program and research on NOS.

The findings regarding the third research question provide supporting evidence
for the three core features of an effective professional development program identified by
Birman, Desimore, Porter, and Garet (2000). Based on literature review and survey data,
Birman and her colleagues (2000) claimed that a professional development program
would be more likely to be effective (a) if it focuses on improving and deepening
teachers’ content knowledge in addition to knowledge of how students learn particular
content (content focus), (b) if it provides opportunities for active learning of teachers
(active learning), and (c) if it fosters a coherent set of learning experiences (coherence).
In this study, the elementary teachers also found the professional development program
effective because they perceived that they knew more about the NOS content and how to
teach this content in their classrooms. Moreover, they felt that they were provided ample
opportunities to construct their own NOS understandings through participating in hands-
on NOS activities, reading about NOS, reviewing elementary students’ NOS ideas, and
teaching NOS in their classrooms. Finally, they perceived that consistently making
references to the NOS aspects after each NOS training activity, matching the content of
the professional development program with national and state science standards, and
implementing several NOS activities in their own classroom encouraged coherence in
their learning experiences.
Birman and her colleagues (2000) also asserted that the core features of a professional development experience (i.e., content focus, active learning, and coherence) would be more likely to be activated (a) if the professional development program uses reform formats such as study group and teacher network in contrast to a traditional workshop or conference (reform vs. traditional format), (b) if the professional development program ensures longer duration of professional development activities (shorter vs. longer in duration), and (c) if the professional development program supports participation of teachers from the same school, subject matter, or grade level as opposed to the participation of individual teachers from many schools (collective vs. individual participation). Consistent with Birman et al. (2000), the findings of this study also underscored the indirect impact of certain structural features on the effectiveness of the professional development program. These structural features included the following: (a) multiple exposures to the NOS aspects through an extended amount of time, (b) allocating specific time for discussing the NOS aspects and NOS activities with peers both as a learner and a teacher, and (c) the opportunity to test what was learned during the NOS training with their own students.

The identification of effective components of the professional development program in the present study also contributes to the NOS literature because in previous studies with elementary teachers, a great number of researchers (Abd-El-Khalick, 2001; Akerson et al. 2000; Akerson et al., 2007, Celik & Bayrakceken, 2012; Dass, 2005, Koening et al., 2012; Matkins & Bell, 2007; Salter & Atkins, 2013) mainly focused on tracking changes in elementary teachers’ conceptions of NOS after some types of NOS instruction. In this study, the components perceived influential in the elementary science
teachers’ conceptions of NOS show similarities and differences with the findings of previous studies. For instance, making the NOS aspects the focus of the instruction, doing hands-on activities or readings on NOS, and reflecting on the learning experience from the perspective of NOS draw a parallel with the explicit-reflective instructional approach called by Abd-El-Khalick and Lederman (2000). The present study reiterated that intentionally drawing learners’ attention to the NOS aspects through reflection in the context of activities or reading was effective in improving NOS conceptions of elementary science teachers (Abd-El-Khalick, 2001; Akerson et al., 2000; Akerson et al., 2007; Celik & Bayrakceken, 2012; Dass, 2005; Koeing et al., 2012). Different from previous studies, the findings suggested the importance of different types/ formats of structured reflection for NOS learning of elementary teachers or students. Based on their learning and teaching experience, the participants perceived that effective NOS instruction at the elementary grade levels should provide an opportunity for students to reflect on the activity themselves via answering thoughtfully constructed guiding questions because such structured self-reflection forms a basis for grappling with different ideas in discussions with peers. That is, writing self-reflection should be followed by oral reflection as a whole class or a small group of peers in order to make meaningful connections between the learning experience and the NOS content. The use of both written and oral reflection in NOS instruction with elementary teachers or students seemed to be supported by Yinger and Clark (1981) who argued that writing down ideas emerged from reflection is more powerful than reporting them orally.

In addition to the use of different types/ formats of structured reflection, the findings revealed that the elementary teachers perceived the visual aids (i.e., the NOS
poster and the definition list for the NOS aspects), doing interviews with the researcher, and assessing elementary students’ NOS ideas influential in their learning of NOS because these professional development activities helped them to reflect on what they were learning in ways that allow them to deeply conceptualize and retain the target content. In this regard, the study findings support the suggestion of Abd-El-Khalick and Akerson (2009) about the use of metacognitive strategies to increase the effectiveness of explicit-reflective NOS instruction. In their study, Abd-El-Khalick and Akerson (2009) provided opportunities for the intervention group participants to involve with thinking about NOS as they constructed concept maps, interviewed peers about their NOS ideas, and responded to case studies. They found that preservice elementary teachers who received explicit-reflective NOS instruction coupled with training in, and the use of, the three metacognitive strategies made statistically more gains in their views of the target NOS aspects than those who received only explicit-reflective NOS instruction.

**Implications**

The findings of this study have several implications for teachers and researchers in the fields of science education and teacher education. First, the findings of this study put forward that elementary teachers are not sufficiently exposed to the NOS content and how to teach this content to their students in their teacher education programs. They mostly acquire an understanding of what science is or how science operates as a by-product of their learning experience in science courses. Unfortunately, elementary teachers do not perceive this implicitly acquired NOS knowledge sufficient to convey it to their own students. Given that one cannot be expected to teach a topic without having enough content knowledge, the findings of this study recommend for elementary teachers
to complete more courses on science and philosophy of science in their teacher education programs. The researcher acknowledges that simply taking more courses would not ensure teachers’ acquisition of functional NOS content knowledge, but it can help them to form a basis for this science content prior to actually teaching it in their own classrooms. This foundation on NOS could be supported with the development of more professional development programs that are particularly designed to improve teachers’ content and pedagogical knowledge on NOS. In other words, the findings of this study call for not only more undergraduate courses but also more professional development programs that make NOS focus of the instruction.

Second, the findings of this study suggest that teachers should be given more opportunities to practice what was learned in a professional development program with their own students. In agreement with Guskey (1985, 1986, 2002), practicing new ideas and practices is considered as a precursor to changing teachers’ beliefs about teaching. The findings of this study indicate that teachers seek for concrete evidence about to what extent their students could understand, and benefit from learning, the new ideas while making decisions about the inclusion of these particular ideas in their classroom practice. In this regard, practicing what was learned in a professional development program with their own students provides a safe setting for teachers to collect such evidence about their students’ learning and then to make necessary changes in their beliefs and subsequent classroom practice. In addition to changing beliefs, such practices help teachers to clarify or enhance their content and pedagogical content knowledge. With that being said, the study findings suggest that the act of teaching should be considered as an integral part of
inservice teacher education in order to bring about changes in teachers’ beliefs and their classroom practices.

Third, the findings of this study have methodological implications about the assessment of elementary teachers’ NOS conceptions. The VNOS-D2 questionnaire (Lederman & Khishfe, 2002) used in the present study was designed to assess NOS conceptions of elementary teachers. However, the study findings indicated that certain questions on the questionnaire (i.e., question about how scientists determined the structure of an atom) fail to tap into elementary teachers’ NOS conceptions because of their lack of science content knowledge. Therefore, additional research is warranted concerning how to better assess inferential NOS conceptions of elementary teachers with open-ended questionnaires. Furthermore, the study findings suggest that classification of teachers’ NOS conceptions into predetermined categories (e.g., an ‘inadequate’, ‘adequate’, or ‘informed’ conception of the target NOS aspects [Morrison et al., 2009]) does not fully capture the changes in the learners’ NOS conceptions as a result of an instructional intervention. This suggestion is warranted with the criticisms made about the use of standardized and convergent paper and pencil NOS instruments in the assessment of students’ and teachers’ NOS conceptions. As Lederman et al. (1998) highlighted, the instruments with forced-choice response format (e.g., agree/disagree, a Likert-type scale, or multiple choice response) impose the researchers’ or instrument developers’ NOS conceptions on students or teachers. Similarly, the use of predetermined NOS categories can also impose researchers’ NOS views on the participants.

Finally, the findings of this study have methodological implications about the assessment of teachers’ beliefs about the developmental appropriateness and importance
of the NOS aspects. Sweeney (2010) was the first researcher who measured teachers’ beliefs about the developmental appropriateness and importance of the NOS aspects via developing a questionnaire called The Ideas about Science for Early Elementary (K-4) Students. In this paper and pencil instrument, the respondents are provided with the definitions of certain ideas about science in order to make decisions about the developmental appropriateness and importance of introducing these ideas in K-4 classrooms. The study findings indicate that this questionnaire is based on a problematic assumption as such that the respondents interpret the given definitions and the terms “developmental appropriateness” and “importance” in a manner similar to that of the instrument developer. Therefore, the findings of this study suggest that this instrument should be used together with a follow-up interview to avoid such ambiguities, which seriously threaten the instrument’s validity.

**Limitations of the Study**

The present study had several limitations. First, the findings of this exploratory study are applicable to the four elementary science teachers who worked at a high achieving school giving high emphasis on science. Accordingly, the impacts of the professional development program employed in this study were determined from data obtained from the four elementary science teachers at this school. Considering previous studies (Akerson et al., 2009a; Akerson et al., 2009b) had documented the influence of contextual variables (e.g., what is valued in the district or at the school) on NOS learning, the impacts of the professional development program could vary at other schools which do not give much emphasis on science. Further research is needed to determine whether the findings apply to other teacher groups teaching in lower achieving schools.
Second, the participants of the present study were not so diverse in terms of the grade level that they taught science. There was only one third-grade teacher. Other participants were all fifth grade teachers. Given that discussing ideas with other teachers plays a significant role in teachers’ professional development (Bell & Gilbert, 1996), the third grade teacher might not have as much opportunities as her fifth grade counterparts to exchange her ideas during discussions. If there were other third grade teachers, she would be more likely to challenge her NOS conceptions or beliefs about the developmental appropriateness and importance of teaching the nine NOS aspects.

Third, the type of changes observed in NOS conceptions and beliefs about the developmental appropriateness and importance of the target NOS aspects were applicable to the four participants selected for investigation in this study because at the beginning of the study the participants already had adequate conceptions about certain NOS aspects and they already believed that it is appropriate and important to teach NOS at the elementary grade levels. Given that prior knowledge or beliefs mediate one’s learning (Pintrich et al., 1993; Posner et al., 1982; Strike & Posner, 1992), different group of participants who start the professional development with more naïve NOS conceptions or negative beliefs about teaching NOS might show different type of changes. In addition to the type of changes, such group of participants might perceive different components influential in their NOS conceptions and beliefs about the developmental appropriateness and importance of the target NOS aspects. Therefore, further research is needed to determine whether the study findings are applicable to other participants group.
### Appendix A: Description of Nature of Science Aspects

<table>
<thead>
<tr>
<th>NOS aspect</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empirical NOS</td>
<td>Scientific knowledge is based on observations of the natural world. These observations are also called evidence, facts, or data.</td>
</tr>
<tr>
<td>Inferential NOS</td>
<td>Science is based on both observation and inference. Observation is the process of using the five senses to gather information about the natural world. Inference is the process of reaching logical conclusions based on observations.</td>
</tr>
<tr>
<td>Creative NOS</td>
<td>Science is a creative process. This means that scientists use their imaginations and creativity when planning and carrying out investigations and making sense of the data.</td>
</tr>
<tr>
<td>Subjective NOS</td>
<td>Scientific knowledge is not entirely objective. This means that personal values, prior knowledge and experience affect what scientists study and how they do science.</td>
</tr>
<tr>
<td>Tentative NOS</td>
<td>Scientific knowledge is tentative. This means that the current scientific knowledge is the best we have at this time, but it may change in the future with new evidence or new interpretations of old evidence.</td>
</tr>
<tr>
<td>Scientific Methods</td>
<td>There is not a single step by step “scientific method” by which all science is done. Scientists use a variety of methods. However, scientific investigation usually involves collecting evidence, using logical reasoning, and making predictions and explanations based on the evidence.</td>
</tr>
<tr>
<td>Sociocultural NOS</td>
<td>Science influences and is influenced by the society and culture in which it is practiced. Men and women of many societies and cultures have contributed to science.</td>
</tr>
<tr>
<td>Collaborative NOS</td>
<td>Scientists may work in teams or work alone, but all communicate with each other, share their knowledge, and critically review each other’s work.</td>
</tr>
<tr>
<td>Limit/ Bounded NOS</td>
<td>Science cannot answer all questions. Science is appropriate for understanding the natural world but it cannot answer questions related to art, philosophy, religion, or ethics.</td>
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</tbody>
</table>

*Note. Adapted from Sweeney (2010). Factors affecting early elementary (K-4) teachers’ introduction of the nature of science: A national survey. (Unpublished PhD). University of Arkansas, Fayetteville, AR.*
DATE: December 20, 2013
TO: Dr. Hasan Deniz, Teaching & Learning
FROM: Office of Research Integrity – Human Subjects
RE: Notification of IRB Action
Protocol Title: Investigating Elementary Teachers’ and their Students’ Views about Nature of Science
Protocol # 1308-4526

This memorandum is notification that the project referenced above has been reviewed as indicated in Federal regulatory statutes 45CFR46 and deemed exempt under 45 CFR 46.101(b)1.

PLEASE NOTE:
Upon Approval, the research team is responsible for conducting the research as stated in the exempt application reviewed by the ORI – HS and/or the IRB which shall include using the most recently submitted Informed Consent/Assent Forms (Information Sheet) and recruitment materials. The official versions of these forms are indicated by footer which contains the date exempted.

Any changes to the application may cause this project to require a different level of IRB review. Should any changes need to be made, please submit a Modification Form. When the above-referenced project has been completed, please submit a Continuing Review/Progress Completion report to notify ORI – HS of its closure.

If you have questions or require any assistance, please contact the Office of Research Integrity - Human Subjects at IRB@unlv.edu or call 895-2794.
Appendix C: Views of Nature of Science Questionnaire

Instructions:

☐ Please answer each of the following questions. Include relevant examples whenever possible.

☐ There are no “right” or “wrong” answers to the following questions. I am only interested in your opinion on a number of issues about science.

1. What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?

2. What is an experiment?

3. Does the development of scientific knowledge require experiments?
   - If yes, explain why. Give an example to defend your position.
   - If no, explain why. Give an example to defend your position.

4. After scientists have developed a theory (e.g., atomic theory, kinetic molecular theory, cell theory, evolution theory), does the theory ever change?
   - If you believe that scientific theories do not change, explain why and defend your answer with examples.
   - If you believe that theories do change:
     (a) Explain why theories change?
     (b) Explain why we bother to teach and learn scientific theories. Defend your answer with examples.

5. Science textbooks often represent the atom as a central nucleus composed of positively charged particles (protons) and neutral particles (neutrons) with negatively charged particles (electrons) orbiting the nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?

6. How are science and art similar? How are they different?

7. Scientists perform experiments/investigations when trying to solve problems. Other than the planning and design of these experiments/investigations, do scientists use their creativity and imagination during and after data collection? Please explain your answer and provide examples if appropriate.

8. Is there a difference between scientific knowledge and opinion? Give an example to illustrate your answer.

9. Some astronomers believe that the universe is expanding while others believe that it is shrinking; still others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible if all of these scientists are looking at the same experiments and data?
Appendix D: Beliefs about the Developmental Appropriateness and Importance of Specific Nature of Science Aspects Questionnaire

Ideas about Science Questionnaire

You have been invited to participate in this research because of your expertise regarding what is important and developmentally appropriate to teach elementary students. It is very important that you complete the entire questionnaire. Please answer all questions to the best of your ability. Thank you for your valuable time.

Q1. Science is based on both observation and inference. Observation is the process of using the five senses to gather information about the natural world. Inference is the process of reaching logical conclusions based on observations.

To what extent do you feel this idea is developmentally appropriate for the grade level(s) you currently teach?
5. Very appropriate
4. Somewhat appropriate
3. Neither appropriate nor inappropriate
2. Slightly appropriate
1. Not at all appropriate
Please describe the reason for your rating for this idea.
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

How important do you feel it is to teach this idea for the grade level(s) you currently teach?
5. Very important
4. Somewhat important
3. Neither important nor unimportant
2. Slightly important
1. Not at all important
Please describe the reason for your rating for this idea.
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

Which statement best describes your actions or plans for teaching this idea?
1. I already taught this idea this school year.
2. I plan to teach this idea (this/ next school year) (by the end of this semester).
3. I will not teach this idea (this/ next school year) (by the end of this semester).
(4. I do not plan to teach this idea at all.)
Q2. Science is a creative process. This means that scientists use their imaginations and creativity when planning and carrying out investigations and making sense of the data.

To what extent do you feel this idea is developmentally appropriate for the grade level(s) you currently teach?
5. Very appropriate
4. Somewhat appropriate
3. Neither appropriate nor inappropriate
2. Slightly appropriate
1. Not at all appropriate
Please describe the reason for your rating for this idea.
___________________________________________________________________
___________________________________________________________________

How important do you feel it is to teach this idea for the grade level(s) you currently teach?
5. Very important
4. Somewhat important
3. Neither important nor unimportant
2. Slightly important
1. Not at all important
Please describe the reason for your rating for this idea.
___________________________________________________________________
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Which statement best describes your actions or plans for teaching this idea?
1. I already taught this idea this school year.
2. I plan to teach this idea (this/ next school year) (by the end of this semester).
3. I will not teach this idea (this/ next school year) (by the end of this semester).
(4. I do not plan to teach this idea at all.)
Q3. Scientific knowledge is tentative. This means that the current scientific knowledge is the best we have at this time, but it may change in the future with new evidence or new interpretations of old evidence.

To what extent do you feel this idea is developmentally appropriate for the grade level(s) you currently teach?
5. Very appropriate
4. Somewhat appropriate
3. Neither appropriate nor inappropriate
2. Slightly appropriate
1. Not at all appropriate

Please describe the reason for your rating for this idea.
___________________________________________________________________
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How important do you feel it is to teach this idea for the grade level(s) you currently teach?
5. Very important
4. Somewhat important
3. Neither important nor unimportant
2. Slightly important
1. Not at all important

Please describe the reason for your rating for this idea.
___________________________________________________________________
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Which statement best describes your actions or plans for teaching this idea?
1. I already taught this idea this school year.
2. I plan to teach this idea (this/ next school year) (by the end of this semester).
3. I will not teach this idea (this/ next school year) (by the end of this semester).
(4. I do not plan to teach this idea at all.)
Q4. Scientific knowledge is based on observations of the natural world. These observations are also called evidence, facts, or data.

To what extent do you feel this idea is developmentally appropriate for the grade level(s) you currently teach?
5. Very appropriate  
4. Somewhat appropriate  
3. Neither appropriate nor inappropriate  
2. Slightly appropriate  
1. Not at all appropriate  
Please describe the reason for your rating for this idea.
___________________________________________________________________  
___________________________________________________________________  
___________________________________________________________________

How important do you feel it is to teach this idea for the grade level(s) you currently teach?
5. Very important  
4. Somewhat important  
3. Neither important nor unimportant  
2. Slightly important  
1. Not at all important  
Please describe the reason for your rating for this idea.
___________________________________________________________________  
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Which statement best describes your actions or plans for teaching this idea?
1. I already taught this idea this school year.  
2. I plan to teach this idea (this/ next school year) (by the end of this semester).  
3. I will not teach this idea (this/ next school year) (by the end of this semester).  
(4. I do not plan to teach this idea at all.)
Q5. Scientific knowledge is not entirely objective. This means that personal values, prior knowledge and experience affect what scientists study and how they do science.

To what extent do you feel this idea is developmentally appropriate for the grade level(s) you currently teach?
5. Very appropriate
4. Somewhat appropriate
3. Neither appropriate nor inappropriate
2. Slightly appropriate
1. Not at all appropriate

Please describe the reason for your rating for this idea.
___________________________________________________________________
___________________________________________________________________

How important do you feel it is to teach this idea for the grade level(s) you currently teach?
5. Very important
4. Somewhat important
3. Neither important nor unimportant
2. Slightly important
1. Not at all important

Please describe the reason for your rating for this idea.
___________________________________________________________________
___________________________________________________________________

Which statement best describes your actions or plans for teaching this idea?
1. I already taught this idea this school year.
2. I plan to teach this idea (this/ next school year) (by the end of this semester).
3. I will not teach this idea (this/ next school year) (by the end of this semester).
(4. I do not plan to teach this idea at all.)
Q6. Science influence and is influenced by the society and culture in which it is practiced. Men and women of many societies and cultures have contributed to science.

To what extent do you feel this idea is developmentally appropriate for the grade level(s) you currently teach?
5. Very appropriate
4. Somewhat appropriate
3. Neither appropriate nor inappropriate
2. Slightly appropriate
1. Not at all appropriate

Please describe the reason for your rating for this idea.

________________________________________________________________________

________________________________________________________________________

How important do you feel it is to teach this idea for the grade level(s) you currently teach?
5. Very important
4. Somewhat important
3. Neither important nor unimportant
2. Slightly important
1. Not at all important

Please describe the reason for your rating for this idea.

________________________________________________________________________

________________________________________________________________________

Which statement best describes your actions or plans for teaching this idea?
1. I already taught this idea this school year.
2. I plan to teach this idea (this/ next school year) (by the end of this semester).
3. I will not teach this idea (this/ next school year) (by the end of this semester).
(4. I do not plan to teach this idea at all.)
Q7. There is not a single step by step “scientific method” by which all science is done. Scientists use a variety of methods. However, scientific investigation usually involves collecting evidence, using logical reasoning, and making predictions and explanations based on the evidence.

To what extent do you feel this idea is developmentally appropriate for the grade level(s) you currently teach?
5. Very appropriate
4. Somewhat appropriate
3. Neither appropriate nor inappropriate
2. Slightly appropriate
1. Not at all appropriate
Please describe the reason for your rating for this idea.
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

How important do you feel it is to teach this idea for the grade level(s) you currently teach?
5. Very important
4. Somewhat important
3. Neither important nor unimportant
2. Slightly important
1. Not at all important
Please describe the reason for your rating for this idea.
___________________________________________________________________
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Which statement best describes your actions or plans for teaching this idea?
1. I already taught this idea this school year.
2. I plan to teach this idea (this/ next school year) (by the end of this semester).
3. I will not teach this idea (this/ next school year) (by the end of this semester).
(4. I do not plan to teach this idea at all.)
Q8. Scientists may work in teams or work alone, but all communicate with each other, share their knowledge, and critically review each other’s work.

To what extent do you feel this idea is developmentally appropriate for the grade level(s) you currently teach?
5. Very appropriate
4. Somewhat appropriate
3. Neither appropriate nor inappropriate
2. Slightly appropriate
1. Not at all appropriate

Please describe the reason for your rating for this idea.
___________________________________________________________________
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How important do you feel it is to teach this idea for the grade level(s) you currently teach?
5. Very important
4. Somewhat important
3. Neither important nor unimportant
2. Slightly important
1. Not at all important

Please describe the reason for your rating for this idea.
___________________________________________________________________
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Which statement best describes your actions or plans for teaching this idea?
1. I already taught this idea this school year.
2. I plan to teach this idea (this/next school year) (by the end of this semester).
3. I will not teach this idea (this/next school year) (by the end of this semester).
4. I do not plan to teach this idea at all.)
Q9. Science cannot answer all questions. Science is appropriate for understanding the natural world but it cannot answer questions related to art, philosophy, religion, or ethics.

To what extent do you feel this idea is developmentally appropriate for the grade level(s) you currently teach?
5. Very appropriate
4. Somewhat appropriate
3. Neither appropriate nor inappropriate
2. Slightly appropriate
1. Not at all appropriate

Please describe the reason for your rating for this idea.

___________________________________________________________________
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How important do you feel it is to teach this idea for the grade level(s) you currently teach?
5. Very important
4. Somewhat important
3. Neither important nor unimportant
2. Slightly important
1. Not at all important

Please describe the reason for your rating for this idea.

___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

Which statement best describes your actions or plans for teaching this idea?
1. I already taught this idea this school year.
2. I plan to teach this idea (this/ next school year) (by the end of this semester).
3. I will not teach this idea (this/ next school year) (by the end of this semester).
4. I do not plan to teach this idea at all.)
Q10. Please rank order the following ideas about science in terms of their developmental appropriateness for the grade level(s) you currently teach science?

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<thead>
<tr>
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<th>1</th>
<th>2</th>
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<th>6</th>
<th>7</th>
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<th>9</th>
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<tr>
<td>The most appropriate</td>
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<td>The least appropriate</td>
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</table>

Please use one number for each idea.

___ Science is based on both observation and inference.
___ Science is a creative process.
___ Scientific knowledge is tentative.
___ Scientific knowledge is based on observations of the natural world.
___ Scientific knowledge is not entirely objective.
___ Science influence and is influenced by the society and culture in which it is practiced.
___ There is not a single step by step “scientific method” by which all science is done.
___ Scientists may work in teams or work alone.
___ Science cannot answer all questions.
Q11. Please rank order the following ideas about science in terms of their importance for the grade level(s) you currently teach science?

1  2  3  4  5  6  7  8  9
The most important

The least important

Please use one number for each idea.

___ Science is based on both observation and inference.
___ Science is a creative process.
___ Scientific knowledge is tentative.
___ Scientific knowledge is based on observations of the natural world.
___ Scientific knowledge is not entirely objective.
___ Science influence and is influenced by the society and culture in which it is practiced.
___ There is not a single step by step “scientific method” by which all science is done.
___ Scientists may work in teams or work alone.
___ Science cannot answer all questions.
Appendix E: Interview Protocol for the Teachers’ Views of Nature of Science

1. Could you please describe your current ideas about NOS by commenting on and clarifying your response to each question? (At this point the interviewee was provided with their responses on the corresponding questionnaire and s/he was asked to read their responses and comment on and clarify these responses one by one). What did you mean by your response to question number 1?

2. (After the interviewee’s response to each question was explored and clarified, the interviewee was provided with their previous questionnaire and then s/he was asked to familiarize themselves with their earlier responses or refresh their memories concerning their initial responses, and comment on to what extent and how their responses were changed or influenced). Here are your initial responses. I would like you to keep these responses to yourself for now and spend a moment to refresh your memory concerning your initial response for each question one by one. To what extent do you think your current response is similar or different from your previous response? Or do you see any difference in the two answers you wrote for this question? Or do you think your ideas about this question have in some way changed? Or are these two answers you wrote for this question the same or different from each other?

If No, how are they similar?

If Yes, how do you think these two responses are different from each other?
- What you think influenced your ideas about science?
- Do you think the change you expressed might be related to the NOS training (or the NOS teaching in your own classroom)?
  - If Yes, how do you think this change is related to the NOS training (or the NOS teaching in your own classroom)? If you think that your ideas for this question have in some way changed, which kinds of experiences in this training (or during your NOS teaching) do you think mostly influenced your ideas? Can you pinpoint any experience or activity in this NOS training (or during your NOS teaching) that is much more responsible for this change? Which kinds of experiences or activities in this training (or during your NOS teaching) do you think contributed and did not contribute to this change you expressed in your ideas for this question? (Only for post-NOS training interview, if needed, interviewees were provided with a list of activities in the training to refresh their memory concerning what they did so far).
  - If No, how can you explain the change you expressed?
Appendix F: Interview Protocol for the Teachers’ Beliefs about the Developmental Appropriateness and Importance of Specific Nature of Science Aspects

1. Could you please describe your current beliefs about the importance and developmental appropriateness of the presented NOS ideas by commenting on and clarifying your response to each question (At this point the interviewee was provided with his or her corresponding questionnaire and then s/he was asked to read their responses and to comment on and clarify these responses one by one). What did you mean by your response to question number 1?

2. Do you think your beliefs about the importance and developmental appropriateness of the presented NOS idea have in some way changed or influenced? (Only for mid- and post-interviews).

   If No, how do you think your beliefs are similar to each other?
   - What suggestions could you make to a teacher educator about how best to change such beliefs about the developmental appropriateness and importance of the presented idea about science?

   If Yes, how do you think your current beliefs are different?
   - What do you think influenced your beliefs about the developmental appropriateness and importance of the presented idea about science?
   - Do you relate the change you expressed in your belief to the NOS training (or the NOS teaching in your own classroom)?
     - If Yes, how do you think this change in your belief is related to the NOS training (or your NOS teaching)?
     - Which components of this training (or experience during your NOS teaching) helped or did not help you believe teaching this idea about science more or less important/ more or less appropriate for your students? Which components of this training contributed or did not contribute to your beliefs? What suggestions could you make to a teacher educator about how best to change such beliefs about the importance and developmental appropriateness of this idea about science?
## Appendix G: The List of Instructional Materials Used in the NOS Training

<table>
<thead>
<tr>
<th>Instructional Material</th>
<th>The Use of Instructional Material in the NOS training</th>
<th>Reason(s) for Inclusion</th>
<th>Target NOS aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Article on the Myths of NOS (McComas, 1998)</td>
<td>The teachers read and discuss the 15 myths about NOS that are commonly included in science textbooks, in classroom discourse and in the minds of students and teachers.</td>
<td>The previous use of the article with teachers (Abd-El-Khalick &amp; Akerson, 2004; Akerson et al., 2006; Morrison et al., 2009) To familiarize teachers with contemporary conceptions of NOS; To create dissatisfaction with existing ideas about science or generate cognitive dissonance to make participants explicitly aware of the inadequacies of their NOS conceptions at the beginning of the intervention and help them to seek alternative views consistent with contemporary conceptions of NOS during the rest of the intervention (Abd-El-Khalick &amp; Akerson, 2004; Akerson et al., 2000; McDonald, 2010; Schwartz &amp; Lederman, 2002); To convince teachers about the need for change to address the personal development component of Bell and Gilbert’s (1996) model.</td>
<td>All nine NOS aspects</td>
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<tr>
<td>Bottle</td>
<td>During this NOS activity, the instructor puts a string in a bottle and then flips over the bottle. Learners predict whether the bottle will fall down or stay in the air when released and then draw different models to explain the phenomenon.</td>
<td>The previous use of Black-box Activities with elementary teachers (Abd-El-Khalick &amp; Akerson, 2004; Akerson et al., 2009a; Akerson et al., 2007; Akerson et al., 2006; Donnelly &amp; Argyle, 2011; Koening et al., 2012; Matkins &amp; Bell, 2007; Posnanski, 2010)</td>
<td>All nine NOS aspects</td>
</tr>
<tr>
<td>Instructional Material</td>
<td>The Use of Instructional Material in the NOS training</td>
<td>Reason(s) for Inclusion</td>
<td>Target NOS aspects</td>
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<td>Seven Blind Mice</td>
<td>In this children book, six different-colored blind mice investigate the strange Something by the pond. And one by one, they come back with a different theory. It is the only when the seventh mouse goes out-and explores the complete Something—that the mice see the big picture.</td>
<td><em>Children Literature</em>, suggested by Akerson, Weiland, Pongsanon, &amp; Nargund (2010) to introduce or reinforce NOS aspects for young children  The previous use of children’s literature books with elementary teachers (e.g., Akerson et al., 2000; Akerson et al., 2007) To reinforce NOS aspects</td>
<td>Empirical, inferential, tentative, creative, sociocultural, collaborative, and subjective NOS aspects</td>
</tr>
<tr>
<td>What Do You Do With a Tail Like This?</td>
<td>In this reading, teachers see noses, ears, tails, eyes, feet, and mouths of different animals. Then they infer which animal each part belongs to and how it is used.</td>
<td><em>Children Literature</em>, suggested by Akerson and her colleagues (2010) to introduce or reinforce NOS aspects for young children  The previous use of children’s literature books with elementary teachers (e.g., Akerson et al., 2000; Akerson et al., 2007) To reinforce NOS aspects</td>
<td>Empirical, inferential, tentative, creative, sociocultural, collaborative, and subjective NOS aspects</td>
</tr>
<tr>
<td>Fossils</td>
<td>During this activity, teachers play the role of a paleontologist. They find a fossil fragment and wonder what organism this fossil fragment came from. They drew their organism and share it during a presentation where they also describe the habitat, diet, behavior, and other characteristics of the organism.</td>
<td><em>Contextualized NOS activity</em> because of the presence of the topic “fossils” in the elementary science curriculum  The previous use of the activity with elementary teachers (Matkins &amp; Bell, 2007; Koening et al., 2012) To reinforce NOS aspects</td>
<td>Empirical, inferential, tentative, creative, sociocultural, collaborative, and subjective NOS aspects</td>
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<td>Instructional Material</td>
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<tr>
<td>Tricky Tracks (Lederman &amp; Abd-El-Khalick, 1998)</td>
<td>During this activity, teachers write down a story about what might have happened as indicated by what they see on three pictures. Then they discuss whether and how their story changes.</td>
<td><em>Decontextualized NOS activity</em></td>
<td>Empirical, inferential, tentative, creative, sociocultural, collaborative, and subjective NOS aspects</td>
</tr>
<tr>
<td>Tangram (Choi, 2004)</td>
<td>In this activity, teachers are given four pieces of a tangram that represent scientific data. Then they arrange these pieces into a square. After being told that recently a new scientific discovery has been made, a new piece of data has been found or a new idea has been presented, they incorporate this new information to their tangram.</td>
<td><em>Decontextualized NOS activity</em></td>
<td>Empirical, inferential, tentative, creative, collaborative, subjective NOS aspects, and the absence of a single scientific method</td>
</tr>
<tr>
<td>Cube (Lederman &amp; Abd-El-Khalick, 1998)</td>
<td>Teachers as a group make observations on the five sides of the cube. Based on their observations, they figure out the pattern on the cube, and consequently infer what is underneath of the cube.</td>
<td><em>Decontextualized NOS activity</em></td>
<td>Empirical, inferential, tentative, creative, sociocultural, collaborative, and subjective NOS aspects</td>
</tr>
<tr>
<td>Instructional Material</td>
<td>The Use of Instructional Material in the NOS training</td>
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<tr>
<td>Article on NOS Teaching Strategies (Akerson et al., 2010)</td>
<td>Teachers read and discuss Akerson and her colleagues’ (2010) article on a research-based model and strategies for teaching NOS to young children.</td>
<td>To address the PD component of Bell and Gilbert’s (1996) model: input of new teaching strategies. To discuss developmental appropriateness and importance of teaching NOS aspects.</td>
<td>NA</td>
</tr>
<tr>
<td>The Analysis of NOS Standards</td>
<td>Teachers examine and compare NOS contents in the three National Science Education Policy Documents (i.e., the Benchmarks for Science Literacy [AAAS, 1993], NSES [NRC, 1996], and NGSS [NGSS Lead States, 2013]) and State Science Standards for K-5 education (See Appendix J for the worksheet prepared by the researcher to facilitate teachers’ reflection on NOS contents in the standards).</td>
<td>Previous use of the examination of local and state benchmarks for NOS references with teachers to develop NOS pedagogical content knowledge (Posnanski, 2010) Previous findings about the impact of teachers’ beliefs about the presence of NOS in the standards on their introduction of NOS in their classrooms (Posnanski, 2010; Sweeney, 2010) To increase teachers’ awareness of the consistent integration of NOS in the major science education policy documents, and thus, to convince teachers about the prominent place of NOS as a valued instructional outcome for K-5 students (for the acknowledgement of the importance and/or developmental appropriateness of teaching NOS).</td>
<td>All nine NOS aspects</td>
</tr>
<tr>
<td>Instructional Material</td>
<td>The Use of Instructional Material in the NOS training</td>
<td>Reason(s) for Inclusion</td>
<td>Target NOS Aspects</td>
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<tr>
<td>NOS Poster</td>
<td>After each NOS activity, the instructors refer to the NOS poster that includes the definitions of the target NOS aspects (See Appendix H for the NOS poster developed by the researcher).</td>
<td>The use of visual aids was suggested by Akerson and her colleagues (2010) to introduce or reinforce NOS aspects for young children.</td>
<td>All nine NOS aspects</td>
</tr>
<tr>
<td>Assessment of Elementary Students’ NOS Ideas</td>
<td>Teachers first individually and then collaboratively categorize given students ideas into an inadequate, adequate, or informed NOS idea for the empirical, inferential, creative, tentative, and subjective NOS (See Appendix K for the worksheet that includes research-based NOS ideas of elementary students organized by the researcher).</td>
<td>Inspired from the NOS card-exchange activity (Cobern &amp; Loving, 1998) to reinforce the acquired NOS views. The analysis of NOS views of students was found effective for improving NOS views of the instructors of preservice elementary teachers (Hanuscin et al., 2006). The use of metacognitive strategies (e.g., developing a chart to track the variety of meanings that could be ascribed to the target NOS aspects) was found effective for improving elementary teachers’ conceptions of NOS in some previous studies (Abd-El-Khalick &amp; Akerson, 2004, 2009). To address the PD component of Bell and Gilbert’s (1996) model: “Teachers will not continue to develop and use new teaching activities if they feel that they are unable to meet requirements for assessment” (p. 23).</td>
<td>Empirical, inferential, creative, tentative, and subjective NOS aspects</td>
</tr>
</tbody>
</table>

305
Appendix H: The NOS Poster

Note. The poster was developed by the researcher using the definitions of NOS aspects on Sweeney’s (2010) questionnaire of Ideas about Science for Early Elementary (K-4) Students.
Appendix I: Structured Reflection Worksheet for the Cube Activity

1. Each student in your group will make observations on the cube surface facing him/her. One student will be “the recorder” who will compile all the data. Based on your observations, your group will figure out the pattern on the cube, and consequently infer what is on the bottom.

<table>
<thead>
<tr>
<th>YOUR OBSERVATION</th>
<th>PATTERNS</th>
<th>YOUR INFEERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>What do you see on each side of the cube?</td>
<td>What patterns did you figure out on the cube?</td>
<td>What is on the bottom of the cube?</td>
</tr>
</tbody>
</table>

2. Discuss whether it is possible to tell which group is “right” and which group is “wrong”.

3. Do you think that people from another country (e.g., China, Turkey, and Spain) would make similar inferences? Why or why not?

4. Do you think that scientists coming from different cultures and backgrounds would come up with different explanations of the same phenomenon?
Appendix I (Continue)

5. How do you think what you have done is similar to the work of scientists? Check each nature of science idea that you recognized during this activity. Write a few key words that show these ideas in the activity.

_____ Science is based on observations:

_____ Science is based on both observation and inference:

_____ Science is a creative process:

_____ Scientific knowledge is not entirely objective:

_____ Scientific knowledge is tentative:

_____ There is not a single step by step “scientific method”:

_____ Science influences and is influenced by the society and culture:

_____ Scientists communicate with each other:

_____ Science cannot answer all questions:
Appendix I (Continue)

CUBE ACTIVITY

Summary: In this activity, as a group you made observations on the five sides of the cube. Based on your observations, your group then figured out the pattern on the cube, and consequently inferred what is on the bottom.

Reflections:

How would you rate the Cube activity on a 1-10 scale in terms of its appropriateness in your class?

(Totally inappropriate) 1 2 3 4 5 6 7 8 9 10 (Totally appropriate)

If you use the Cube activity in your classroom, write how you plan to revise this activity for your classroom (the way you present this activity, language used, questioning, student worksheet, and etc).

Are there any NOS aspects that are relevant in this activity, but you do not plan to teach in your classroom? Yes_____ No_____ Please list NOS aspects, if any, you do not plan to teach and write a few sentences explaining why you do not want to teach those aspects.
Appendix J: The Analysis of NOS Standards

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Empirical:</strong></td>
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<td></td>
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</tr>
<tr>
<td>Scientific knowledge is based on observations of the natural world. These observations are also called evidence, facts, or data.</td>
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<tr>
<td><strong>Inferential:</strong></td>
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</tr>
<tr>
<td>Science is based on both observation and inference. Observation is the process of using the five senses to gather information about the natural world. Inference is the process of reaching logical conclusions based on observations.</td>
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<tr>
<td><strong>Creative:</strong></td>
<td></td>
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<tr>
<td>Science is a creative process. This means that scientists use their imaginations and creativity when planning and carrying out investigations and making sense of the data.</td>
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<tr>
<td><strong>Subjective:</strong></td>
<td></td>
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</tr>
<tr>
<td>Scientific knowledge is not entirely objective. This means that personal values, prior knowledge and experience affect what scientists study and how they do science.</td>
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<tr>
<td><strong>Tentative:</strong></td>
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<tr>
<td>Scientific knowledge is tentative. This means that the current scientific knowledge is the best we have at this time, but it may change in the future with new evidence or new interpretations of old evidence.</td>
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<tr>
<td><strong>Scientific Methods:</strong></td>
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</tr>
<tr>
<td>There is not a single step by step “scientific method” by which all science is done. Scientists use a variety of methods. However, scientific investigation usually involves collecting evidence, using logical reasoning, and making predictions and explanations based on the evidence.</td>
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<tr>
<td><strong>Sociocultural:</strong></td>
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<tr>
<td>Science influences and is influenced by the society and culture in which it is practiced. Men and women of many societies and cultures have contributed to science.</td>
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<tr>
<td><strong>Collaborative:</strong></td>
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<tr>
<td>Scientists may work in teams or work alone, but all communicate with each other, share their knowledge, and critically review each other’s work.</td>
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<tr>
<td><strong>Bounded:</strong></td>
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<tr>
<td>Science cannot answer all questions. Science is appropriate for understanding the natural world but it cannot answer questions related to art, philosophy, religion, or ethics.</td>
<td></td>
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</tr>
</tbody>
</table>
## Appendix K: Assessment of Elementary Students’ NOS Ideas

Please, categorize NOS statements for each NOS aspect by their levels of sophistication (i.e., inadequate, adequate, or informed).

<table>
<thead>
<tr>
<th>NOS Aspect</th>
<th>The Level of Sophistication</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inadequate</strong></td>
<td>“Students did not have a good conception of that particular NOS aspect” (Akerson et al., 2014, p. 254).</td>
</tr>
<tr>
<td><strong>Adequate</strong></td>
<td>“Student could identify and explain most components of the NOS aspect” (Akerson et al., 2014, p. 254).</td>
</tr>
<tr>
<td><strong>Informed</strong></td>
<td>“Students held strong understandings of the NOS concept and could provide examples” (Akerson et al., 2014, p. 254).</td>
</tr>
</tbody>
</table>

Empirical

Inferential

Tentative

Creative

Subjective

After group discussion, what are your final categorizations of NOS statements for each NOS aspect by their levels of sophistication (i.e., inadequate, adequate, or informed)?

<table>
<thead>
<tr>
<th>NOS Aspect</th>
<th>The Level of Sophistication</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inadequate</strong></td>
<td>“Students did not have a good conception of that particular NOS aspect” (Akerson et al., 2014, p. 254).</td>
</tr>
<tr>
<td><strong>Adequate</strong></td>
<td>“Student could identify and explain most components of the NOS aspect” (Akerson et al., 2014, p. 254).</td>
</tr>
<tr>
<td><strong>Informed</strong></td>
<td>“Students held strong understandings of the NOS concept and could provide examples” (Akerson et al., 2014, p. 254).</td>
</tr>
</tbody>
</table>

Empirical

Inferential

Tentative

Creative

Subjective
Appendix K (Continue): Research Based NOS Ideas of Elementary Students

<table>
<thead>
<tr>
<th>NOS Idea of the Elementary Student</th>
<th>Level of the NOS Idea</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inferential 1:</strong></td>
<td></td>
</tr>
<tr>
<td>Question: How did scientists know that dinosaurs existed?</td>
<td>Adequate</td>
</tr>
<tr>
<td>3rd grade student: “Scientists saw the dinosaurs so they know how to put them together” (Akerson et al., 2014, p. 254).</td>
<td></td>
</tr>
<tr>
<td><strong>Inferential 2:</strong></td>
<td>Adequate</td>
</tr>
<tr>
<td>Question: How did scientists know that dinosaurs existed?</td>
<td>Adequate</td>
</tr>
<tr>
<td>4th grade student: “Because it came from cavemen who saw them and told lots of other ancestors, and then to us. That is how I think scientists think dinosaurs existed. Not just that they got the fossils from the dinosaurs but that someone saw them, too.” (Akerson &amp; Abd-El-Khalick, 2005, p. 5).</td>
<td></td>
</tr>
<tr>
<td><strong>Inferential 3:</strong></td>
<td>Informed</td>
</tr>
<tr>
<td>Question: How did scientists determine what the inside of the earth looked like?</td>
<td>Informed</td>
</tr>
<tr>
<td>4th grade student: “Scientists drill about ten miles into the earth and tell what they know about what they see from drilling. Then they do some other stuff, like set up machines that track waves during the earthquakes. When they do the earthquake measurement, the waves show that there has to be some kind of liquid in the middle of the earth because the waves don’t go all the way through to the other side. They can’t see the inside, but they know stuff from tests.” (Akerson &amp; Abd-El-Khalick, 2005, p. 6).</td>
<td></td>
</tr>
<tr>
<td><strong>Inferential 4:</strong></td>
<td>Adequate</td>
</tr>
<tr>
<td>Question: How did scientists know that dinosaurs existed?</td>
<td>Adequate</td>
</tr>
<tr>
<td>4th grade student: “They found the bones and kept finding them until they found all the bones for the body” (Akerson &amp; Abd-El-Khalick, 2005, p. 5).</td>
<td></td>
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<tr>
<td><strong>Inferential 5:</strong></td>
<td>Adequate</td>
</tr>
<tr>
<td>3rd grade student: “Scientists did not see dinosaurs, but found their bones, fossils, and looked at the habitat.” (Akerson et al., 2014, p. 254).</td>
<td></td>
</tr>
<tr>
<td><strong>Inferential 6:</strong></td>
<td>Adequate</td>
</tr>
<tr>
<td>Question: How could scientists tell the color of dinosaurs?</td>
<td>Adequate</td>
</tr>
<tr>
<td>4th grade student: “Well, they know the shape because they have the bones. They just guess about the color of the skin; they keep trying different colors until it looks right.” (Akerson &amp; Abd-El-Khalick, 2005, p. 5).</td>
<td></td>
</tr>
<tr>
<td><strong>Inferential 7:</strong></td>
<td>Adequate</td>
</tr>
<tr>
<td>Question: How did scientists determine what the inside of the earth looked like?</td>
<td>Adequate</td>
</tr>
<tr>
<td>4th grade student: “They dug into the earth” or “[They] used special telescopes [or microscopes, or computers/cameras].” (Akerson &amp; Abd-El-Khalick, 2005, p. 5).</td>
<td></td>
</tr>
<tr>
<td>NOS Idea of the Elementary Student</td>
<td>Level of the NOS Idea</td>
</tr>
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<td>-----------------------------------</td>
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</tr>
</tbody>
</table>
| **Inferential 8:**  
3rd grade student: “Scientists use evidence but they are uncertain about their findings” (Akerson et al., 2014, p. 255). | Adequate |
| **Inferential 9:**  
Question: How could scientist tell the color of dinosaurs?  
4th grade student: “You don’t see a red or blue animal, so they pick the colors of animals that are alive today. They are predicting what the animal looks like based on evidence from today’s animals. So they pick a color that makes sense.” (Akerson & Abd-El-Khalick, 2005, p. 5). | Adequate |
| **Inferential 10:**  
6th grade student: “Scientists use investigations to study their ideas, like they compare animals who live today to the evidence they find about dinosaurs that used to live, and figure out what they might have been like” (Akerson & Hanuscin 2007, p. 672). | Informed |
| **Tentative 1:**  
3rd grade student: “Scientific knowledge is never changed” (Akerson et al., 2014, p. 255). | Inadequate |
| **Tentative 2:**  
3rd grade student: “Scientists change their ideas” (Akerson et al., 2014, p. 255). | Adequate |
| **Tentative 3:**  
3rd grade student: “Scientists don’t change what they know. How would it help if they were dead and then no one read a book about what they knew because they thought it was wrong? Why would they change the book?” (Akerson et al., 2014, p. 260). | Inadequate |
| **Tentative 4:**  
1st grade student: Scientists never change their ideas. “They already found it out, they don’t have to do it again.” (Akerson & Volrich, 2006, p. 389). | Inadequate |
| **Tentative 5:**  
3rd grade student: “Scientists are not certain they are right” (Akerson et al., 2014, p. 255). | Adequate |
| **Tentative 6:**  
| **Tentative 7:**  
Scientists can change their ideas if they get new data or if they look at the old data in a new way (adapted from a fourth grade teacher’s response, Akerson & Abd-El-Khalick, 2003). | Informed |
<table>
<thead>
<tr>
<th>NOS Idea of the Elementary Student</th>
<th>Level of the NOS Idea</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tentative 8:</strong> 3\textsuperscript{rd} grade student: “Scientists discover new evidence and try or invent something new” (Akerson et al., 2014, p. 255).</td>
<td>Adequate</td>
</tr>
<tr>
<td><strong>Tentative 9:</strong> 1\textsuperscript{st} grade student: “In a 1,000 years they will change their mind because they want different things.” (Akerson &amp; Volrich, 2006, p. 389).</td>
<td>Adequate</td>
</tr>
<tr>
<td><strong>Tentative 10:</strong> 4\textsuperscript{th} grade student: “If we get better technology, we know more stuff, so we can add it to the books.” (Akerson &amp; Abd-El-Khalick, 2005, p. 7).</td>
<td>Adequate</td>
</tr>
<tr>
<td><strong>Empirical 1:</strong> 1\textsuperscript{st} grade student: “They [scientists] make stuff up like cookies from dough.” (Akerson &amp; Donnelly, 2010, p. 114).</td>
<td>Inadequate</td>
</tr>
<tr>
<td><strong>Empirical 2:</strong> 3\textsuperscript{rd} grade student: “Scientists use evidence and they are sure about their findings” (Akerson et al., 2014, p. 255).</td>
<td>Adequate</td>
</tr>
<tr>
<td><strong>Empirical 3:</strong> 1\textsuperscript{st} grade student: “Scientists figure out things by testing them” (Akerson &amp; Donnelly, 2010, p. 114).</td>
<td>Adequate</td>
</tr>
<tr>
<td><strong>Empirical 4:</strong> 3\textsuperscript{rd} grade student: “Scientists found bones” (Akerson et al., 2014, p. 254).</td>
<td>Adequate</td>
</tr>
<tr>
<td><strong>Empirical 5:</strong> 2\textsuperscript{nd} grade student: “[Scientists] study stuff to make your life easier” (Akerson &amp; Donnelly, 2010, p. 115).</td>
<td>Inadequate</td>
</tr>
<tr>
<td><strong>Empirical 6:</strong> 2\textsuperscript{nd} grade student: “Scientists learn things through observations and experiments” (Akerson &amp; Donnelly, 2010, p. 115).</td>
<td>Adequate</td>
</tr>
<tr>
<td><strong>Empirical 7:</strong> 6\textsuperscript{th} grade student: “Scientists use investigations to study their ideas, like they compare animals who live today to the evidence they find about dinosaurs that used to live, and figure out what they might have been like” (Akerson &amp; Hanuscin 2007, p. 672).</td>
<td>Informed</td>
</tr>
<tr>
<td><strong>Creative 1:</strong> 3\textsuperscript{rd} grade student: “Scientists use their creativity and imagination” (Akerson et al., 2014, p. 255).</td>
<td>Adequate</td>
</tr>
<tr>
<td><strong>Creative 2:</strong> 3\textsuperscript{rd} grade student: “Scientists do not use their creativity and imagination” (Akerson et al., 2014, p. 255).</td>
<td>Inadequate</td>
</tr>
<tr>
<td>NOS Idea of the Elementary Student</td>
<td>Level of the NOS Idea</td>
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</tr>
<tr>
<td><strong>Creative 3:</strong> 3rd grade student: “Scientists have to use data/fact and tell the truth” (Akerson et al., 2014, p. 255).</td>
<td>Inadequate</td>
</tr>
<tr>
<td><strong>Creative 4:</strong> 1st grade student: “Scientists use their imaginations to figure out things, like why the dinosaurs died.” (Akerson et al., 2011, p. 544).</td>
<td>Informed</td>
</tr>
<tr>
<td><strong>Creative 5:</strong> 3rd grade student: “Creativity and imagination lead to the wrong answer” (Akerson et al., 2014, p. 255).</td>
<td>Inadequate</td>
</tr>
<tr>
<td><strong>Creative 6:</strong> 3rd grade student: “No, imagination is interesting to think about, but it is not real. There is no way scientists can imagine things and be right about them!” (Akerson et al., 2014, p. 258).</td>
<td>Inadequate</td>
</tr>
<tr>
<td><strong>Creative 7:</strong> 3rd grade student: “There is no way they need to use their imaginations. They have data. Why would you have to imagine it if you can just use your data? There it is right there. You do not have to imagine it or anything.” (Akerson et al., 2014, p. 261).</td>
<td>Inadequate</td>
</tr>
<tr>
<td><strong>Creative 8:</strong> 6th grade student: “They [scientists] imagine how the experiment will turn out, what the evidence means.” (Akerson &amp; Hanuscin 2007, p. 672).</td>
<td>Informed</td>
</tr>
<tr>
<td><strong>Creative 9:</strong> 3rd grade student: “Scientists don’t use their imaginations because they have facts. Why would you have to imagine it if you can use your data?” (Akerson et al., 2014, p. 261).</td>
<td>Inadequate</td>
</tr>
<tr>
<td><strong>Creative 10:</strong> 4th grade student: “Science is real. You have to do a real job; you can’t imagine things.” (Akerson &amp; Abd-El-Khalick, 2005, p. 7).</td>
<td>Inadequate</td>
</tr>
<tr>
<td><strong>Creative 11:</strong> 4th grade student: You “use your imagination in making a hypothesis, in creating experiments—you imagine what they will be like.” (Akerson &amp; Abd-El-Khalick, 2005, p. 7).</td>
<td>Informed</td>
</tr>
<tr>
<td><strong>Creative 12:</strong> 4th grade student: “Yes, they [scientists] are creative in making inferences from their observations.” (Akerson &amp; Abd-El-Khalick, 2005, p. 7).</td>
<td>Informed</td>
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<tr>
<td>NOS Idea of the Elementary Student</td>
<td>Level of the NOS Idea</td>
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</tbody>
</table>
| **Creative 13:**  
1st grade student: “They figure out stuff, like when they use their imaginations to see if the dinosaurs were big, or small, or medium.” (Akerson & Volrich, 2006, p. 389). | Informed |
| **Subjective 1:**  
Question: Why do different scientists disagree on why dinosaurs went extinct though they have the same information?  
3rd grade student: “Scientists have different ideas/opinions” (Akerson et al., 2014, p. 255). | Adequate |
| **Subjective 2:**  
Question: Why do different scientists disagree on why dinosaurs went extinct though they have the same information?  
3rd grade student: “[Scientists] have different ideas about [why dinosaurs became extinct] because they are different scientists and they know different things.” (Akerson et al., 2011, p. 548). | Informed |
| **Subjective 3**  
Question: Why do different scientists disagree on why dinosaurs went extinct though they have the same information?  
| **Subjective 4:**  
3rd grade level: “Scientists maybe see something else in the data than the other ones, they have different ideas about that data.” (Akerson et al., 2014, p. 264). | Adequate |
| **Subjective 5:**  
2nd grade level: “because there are different ways they [dinosaurs] could die … asteroids, earthquakes, or like eating each other.” (Akerson & Donnelly, 2010, p. 117). | Inadequate |
| **Subjective 6:**  
3rd grade level: “Scientists have different evidence” (Akerson et al., 2014, p. 255). | Inadequate |
| **Subjective 7:**  
3rd grade level: “We do not really know what it [dinosaur] looks like. We just see bones and use what we already know to help us figure it out.” (Akerson et al., 2011, p. 548). | Informed |
| **Subjective 8:**  
<table>
<thead>
<tr>
<th>NOS Idea of the Elementary Student</th>
<th>Level of the NOS Idea</th>
</tr>
</thead>
</table>
| **Subjective 9:**  
3rd grade level: “Even though scientists have the same data to look at, they have different ideas. They look at the data differently.” (Akerson et al., 2014, p. 265). | Adequate |
| **Subjective 10:**  
3rd grade level: “No one knows why all the dinosaurs died, they weren’t there. So they just disagree.” (Akerson et al., 2014, p. 258). | Inadequate |
References


Quigley, C., Pongsanon, K., & Akerson, V. L. (2010). If we teach them, they can learn: Young students’ views of nature of science aspects to early elementary students


Sahin, C. T. & Koksal, M. S. (2010). How are the perceptions of high school students and teachers on NOS as a knowledge type presented in schools in terms of ‘importance’ and ‘interest’? *International Journal of Environmental and Science Education, 5*(1), 105-126.


Curriculum Vitae

ELIF ADIBELLI
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EDUCATION

Doctorate
January/2011 - August/2015
Ph.D. in Curriculum and Instruction with an emphasis in Science Education and a cognate in Educational Psychology, University of Nevada, Las Vegas (UNLV), Nevada, U.S.A.

Dissertation Title: A Study of Elementary Teachers’ Conceptions of Nature of Science and their Beliefs about the Developmental Appropriateness and Importance of Nature of Science throughout a Professional Development Program.


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Thesis Title: Investigating Pre-Service Science Teachers’ Epistemological Beliefs in the Domain of Environment through Comparing with Other Domains.

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B.Sc. in Elementary Science Education with a minor in Elementary Mathematics Education and a minor in Mathematics Department, Middle East Technical University, Ankara, Turkey.

CERTIFICATES

October/2012
The Graduate College Research Certificate Program (GCRCP): A professional development program that provides graduate, and select undergraduate, students with the skills and knowledge necessary to initiate, conduct, and successfully conclude research projects.

March/2012
Certification of Appreciation for Presentation at the Graduate & Professional Student Research Forum.
March/ 2011
Certification of Appreciation for Judging Science Fair, Las Vegas, Nevada, U.S.A.

October 2005/ December 2006
Communication skills participation certificate from the Psychological Counseling and Guidance Center at Middle East Technical University, Ankara, Turkey.

PUBLISHED MANUSCRIPT AND BOOK CHAPTER


CONFERENCE PAPERS

2015


2014


2013

2012

2011

2010

2009


2008


POSPERS AT CONFERENCE/SYMPOSIUM


WORK EXPERIENCE

August/2014- May/2015
Graduate Research Assistant in Project Focusing On Crosscutting Concepts to Understand Science (FOCCUS) (http://www.nevadangse.net/framework/project-focus-supporting-new-nvacs-for-science/), Department of Teaching and Learning, College of Education, University of Nevada, Las Vegas.

August/2013- May/2014
Graduate Teaching Assistant, Department of Teaching and Learning, College of Education, University of Nevada, Las Vegas

January/2011-May/2013
Graduate Research Assistant in Project Venture into Scientific Inquiry Organized around Nevada Standards (VISIONS), Department of Teaching and Learning, College of Education, University of Nevada, Las Vegas

November/2007- February/2011
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October/2005-June/2007
Student Assistant, Faculty of Education, Middle East Technical University, Ankara, Turkey

TEACHING EXPERIENCE

University of Nevada, Las Vegas
CIE 543 (Teaching Elementary School Science), EDEL 443 (Teaching Elementary School Science), SSTEM (Saturday Science Technology Engineering and Mathematics Program)

Middle East Technical University
ELE 435 (School Experience), ESME 509 (Educational Inquiry), ELE 420 (Practice Teaching in Elementary Education), ELE 331 (Laboratory Applications in Science I), ELE 477 (Laboratory Applications in Science and Environmental Education), ELE 332 (Laboratory Applications in Science II)