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Exploring Elementary Teachers' Perceptions about the Developmental Appropriateness and Importance of Nature of Science Aspects

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This study explored how four elementary teachers assessed the developmental appropriateness and importance of nine nature of science (NOS) aspects after participating in a yearlong professional development program. A multiple-embedded case study design was employed. 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. Data were analyzed using Yin's (1994, 2003) analytic tactics of pattern matching, explanation building, and cross-case synthesis. The cross-case analysis revealed that our participants used the following criteria separately or in some combination when they were asked to rate NOS aspects in terms of developmental appropriateness and importance: (a) teachers' NOS learning experience, (b) NOS teaching experience, (c) knowledge of their students, (d) knowledge of curriculum, (e) knowledge of school context, and (f) perceptions about the utility value of a NOS aspect or a myth about a NOS aspect. We found that even though our participants did not rank all NOS aspects equally, they considered all nine NOS aspects developmentally appropriate and important enough to be introduced at the elementary level.

Keywords: nature of science, in-service elementary teachers, classroom-based professional learning

INTRODUCTION

It is widely claimed that the goal of science education is to achieve scientific literacy (DeBoer, 2000). In this regard, several American science education reform documents, including the *Benchmarks for Science Literacy* (American Association for the Advancement of Science [AAAS], 1993, 2009), the *National Science Education*

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Standards (National Research Council [NRC], 1996), and the *Next Generation Science Standards* (NGSS Lead States, 2013) 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, 1998). Given that NOS understanding is vital for evaluating scientific claims and processes, an understanding of NOS is considered as a key component of scientific literacy (NRC, 2000).

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 since the 1980s (NGSS Lead States, 2013). For instance, the Benchmarks for Science Literacy (AAAS, 1993, 2009) 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 2061’s 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 appendix 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) identified 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.

Teachers of *all* ages in the U.S. are expected to know and convey an appropriate understanding of NOS recommended in the major science education reforms to their students (AAAS, 1993, 2009; NRC, 1996; NGSS Lead States, 2013). Given that some studies (Akerson, Cullen, & Hanson, 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 reform documents.

Literature review

The studies conducted with elementary teachers can be categorized under four lines of research: (a) NOS intervention studies employing explicit-reflective instruction, (b) studies exploring factors that mediate the development of NOS views, (c) studies exploring elementary teachers' translation of their NOS views into classroom practice and associated student NOS learning, and (d) studies exploring which NOS aspects could or should be taught at the elementary level.

Within the first line of research, science educators (Abd-El-Khalick, 2001; Akerson, Abd-El-Khalick, & Lederman, 2000; Akerson, Hanson, & Cullen, 2007; Celik & Bayrakceken, 2012; Dass, 2005; Koening, Schen, & Bao, 2012; Deniz & Akerson, 2013; Matkins & Bell, 2007; Salter & Atkins, 2013) assessed whether, and to what extent, the implemented intervention was effective in improving elementary teachers' conceptions of NOS. They reported the changes (or lack thereof) in elementary teachers' conceptions of NOS before and after receiving some kinds of NOS instruction. These studies indicated that the explicit-reflective NOS instructional approach was found to be effective in improving elementary teachers' NOS conceptions. However, the improvements in NOS conceptions were not consistent across participants or NOS aspects.

Within the second line of research, science educators (Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & Akerson, 2009; Akerson, Buzzelli, & Eastwood, 2012; Akerson, Morrison, & McDuffie, 2006; Bell, Matkins, & Gansneder, 2011; Hanuscin, Akerson, & Phillipson-Mower, 2006; Matkins, Bell, Irving, & McNall, 2002; McDonald, 2010; Morrison, Raab, & Ingram, 2009; Shim, Young, & Paolucci, 2010) explored what kinds of factors and/or how these factors influenced elementary teachers' NOS learning in addition to assessing the changes in their NOS conceptions. These studies revealed that various factors might impede or facilitate elementary teachers' learning of NOS as in the learning of any subject matter: (a) *cognitive factors* such as deep vs. surface orientation to learning (Abd-El-Khalick & Akerson, 2004), perceived previous knowledge on NOS (McDonald, 2010), level of cognitive or epistemological development (Akerson et al., 2006), and metacognition (Abd-El-Khalick & Akerson, 2009), (b) *motivational factors* such as perceptions of the importance and utility of learning and teaching NOS (Abd-El-Khalick & Akerson, 2004; McDonald, 2010), (c) *contextual factors* such as the characteristics of the given NOS instruction (e.g., Abd-El-Khalick & Akerson, 2009; Bell et al., 2011; Matkins et al., 2002; McDonald, 2010), and (d) *personal factors* such as academic backgrounds (e.g., Hanuscin et al., 2006; Morrison et al., 2009; Shim et al., 2010), cultural values (Akerson et al., 2012), and religiously compatible worldviews (Abd-El-Khalick & Akerson, 2004).

Within the third line of research, science educators (Akerson & Abd-El-Khalick, 2003; Akerson et al., 2009a; Akerson & Hanuscin, 2007; Akerson, Townsend, Donnelly, Hanson, Tira, & White, 2009b; Deniz & Adibelli, 2014; Cullen, Akerson, & Hanson, 2010; Donnelly & Argyle, 2011; Posnanski, 2010) explored how elementary teachers translated their newly acquired NOS conceptions into classroom practice and/or how these teachers influenced their students' NOS conceptions. These studies showed that there is no direct relationship between teachers' NOS content knowledge and their classroom practice. In other words, having informed understandings of NOS is necessary, but not sufficient for teachers to effectively teach about NOS to their own students (Lederman, 1992). Similar to the second line of research, elementary teachers' translation of NOS conceptions were mediated by various factors: (a) *cognitive factors* such as teachers' science content knowledge (Akerson & Abd-El-Khalick, 2003; Akerson et al., 2009a), (b) *motivational factors* such as perception about the ability or need to incorporate NOS in the classroom (Posnanski, 2010), and (c) *contextual factors* such as what is valued to teach in the school (Akerson et al., 2009a), the support of the superintendent in the school district (Akerson et al., 2009a), and whether the school is located in urban, suburban or rural area (Donnelly & Argyle, 2011).

The last line of research (Akerson, Buck, Donnelly, Nargund-Joshi, & Weiland, 2011; Akerson & Donnelly, 2010; Quigley, Pogsanon, & Akerson, 2010; Sweeney, 2010) explored which NOS aspects could or should be taught at the elementary level. The number of studies in this line of research is relatively small compared to the first three lines. Most of the studies in this line of research were conducted by Akerson and her colleagues. They reached a conclusion about the developmental appropriateness, and implicitly about the importance, of NOS aspects based on the extent to which elementary students understood the NOS aspects targeted in the given science instruction. Akerson and her colleagues chose to focus on certain NOS aspects that they deemed relevant to lower elementary students from the list of NOS aspects endorsed by NSTA. In general, they found that early elementary students can learn about empirical, inferential, tentative, creative, and subjective/sociocultural NOS aspects. In light of their previous empirical studies, Akerson, Cullen, and Hanson (2010) suggested that elementary students should learn more concrete NOS aspects (empirical, inferential, creative, and tentative NOS aspects) earlier than more abstract NOS aspects (subjective or sociocultural NOS aspects).

Unlike the five NOS aspects that are generally targeted in Akerson and her colleagues' studies, Sweneey (2010) cast a wider net by exploring the developmental appropriateness and importance of 12 NOS aspects. In addition, Sweeney (2010) specifically provided teachers opportunity to express their ideas on the developmental appropriateness and importance of these 12 NOS aspects. In her study, Sweeney developed a questionnaire through which K-4 teachers were asked to rate the developmental appropriateness and importance of 12 NOS aspects after reading their brief definitions. More than 90 % of the teachers reported that the inferential, empirical, and creative aspects of the NOS were developmentally appropriate for the grade level taught. They rated the importance of 12 NOS aspects by using 5-point scale *(0=not at all important* and *4 =very important).* She found that the mean scores of eight NOS aspects were at least *somewhat important* to include in K-4 science classrooms. These eight NOS aspects included the inferential, empirical, creative, collaborative, cultural, and tentative NOS, along with the ideas that replication is an important aspect of experimental research and that no single stepwise scientific method exists.

Given that most elementary teachers do not hold adequate conceptions of NOS aligned with the science education policy documents (Lederman, 2007) we think that teachers are not in a position to make informed decisions about the developmental appropriateness and importance of NOS aspects even if the definitions of NOS aspects are provided. It is likely that teachers interpret these NOS aspects from their own perspective when they are asked to assess the developmental appropriateness and importance of NOS aspects. There is a need for further research investigating teachers' perceptions of the developmental appropriateness and importance of NOS aspects after ensuring that teachers have necessary NOS understanding and NOS teaching experience. Therefore, the present study aimed to explore how elementary teachers assessed the developmental appropriateness and importance of NOS aspects after participating a yearlong professional development program about NOS including practice teaching NOS in their own classrooms.

METHODOLOGY

Design

The present study employed a qualitative case study approach to explore elementary teachers' beliefs about the developmental appropriateness and importance of NOS aspects following a professional development program. The case-study approach was purposefully used because of its ability to investigate "a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly confident" (Yin, 1994, 2003, p. 13). In other words, the use of a case study approach enabled the researchers to investigate the developmental appropriateness and importance of NOS aspects in depth and within the context of the elementary school setting. Among four types of case study designs, the present study used an embedded multiple case study design (Yin, 1994, 2003). Each case in this study was an elementary teacher who voluntarily participated in the professional development program, including practice teaching NOS in their own classrooms. Within each case, the researchers focused on beliefs about the developmental appropriateness and importance of NOS and analyzed these units across nine NOS aspects with data from a variety of sources.

Participants and setting

The participants of this study worked at a high achieving public charter school located in the southwest region of the United States. The fact that prior to the study we established a working professional relationship with the school administration and the teachers, and the school placed a special emphasis on science teaching and teacher professional development created a conducive environment for this study. This helped us to maximize the number of elementary teachers participating in the study 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).

Of eight science teachers at the elementary school, four of them volunteered to participate and showed their commitment to complete the professional development program, including both instruction and opportunities to practice teaching about NOS. Three of the participants were fifth grade teachers. Francine was the only third grade teacher in this study. All of the participants were certificated in Elementary K-8 Education. They all reported that on average they spent four to five hours teaching science each week. All of the participants except Nancy had at least five years of elementary science teaching experience. Nancy had three years of teaching experience but she was in her first year of science teaching when the study started. We used a pseudonym for each participant.

Table 1. Background Information of the Study Participants

Case	Age	Grade Level Taught	Years of Teaching Experience	Number of College Science Courses
Francine	36	3rd	5	3
Anna	42	5th	8	5
Nancy	45	5th	3	3
Andy	32	5th	8	7

The professional development program about NOS

The professional development program employed in this study was informed by the explicit-reflective NOS instruction (Abd-El-Khalick, 2001) and the teacher development model (Bell & Gilbert, 1996). Explicit-reflective instruction purposefully makes NOS aspects visible to the learner by drawing learners' attention to relevant NOS aspects through discussion and reflection. While *the explicit* part of explicit-reflective NOS instruction refers to making NOS aspects visible to the learner, *the reflective* part refers to encouraging learners to revise their NOS ideas in light of new ideas they encounter about NOS. Bell and Gilbert's (1996) teacher development model allowed us to structure our professional development program by considering personal, social, and contextual nature of the professional development.

During the explicit-reflective NOS instruction, we 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 (See Appendix A for the definitions of the nine NOS aspects). In this regard, we used hands-on NOS activities, readings, and visual aids included in previous research with elementary teachers or students (See Appendix B for the list of instructional materials). Moreover, we used discussion and questioning to intentionally draw teachers' attention to relevant NOS aspects during the instruction while we encouraged them to revise their NOS ideas in light of new NOS ideas they are presented.

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 we 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 part because of their 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 we 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.

We intentionally made the act of NOS teaching an integral part of the professional development program. Therefore, the professional development program 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 one hour 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 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 phase. Participants also met once to collectively reflect on their NOS teaching and their students' experience in learning NOS.

DATA SOURCES

The study data were collected from multiple sources. The primary data source was Sweeney's (2010) Ideas about Science for Early Elementary (K-4) Students questionnaire coupled with a follow-up interview. This questionnaire was designed to assess elementary teachers' perceptions about the developmental appropriateness and importance of *ideas about science* (NOS aspects) rather teachers' knowledge about NOS aspects. We administered the questionnaire and conducted associated interviews at the end of the professional development program because we wanted to make sure that our participants had the required NOS knowledge and NOS teaching experience before they assessed the developmental appropriateness and importance of NOS aspects. Secondary data sources included The Views of Nature of Science Questionnaire-Form VNOS-D2 (Views of Nature of Science Elementary School Version 2; Lederman & Khishfe, 2002) coupled with both follow-up interviews and the researcher's reflective field notes. The administration of the NOS instrument allowed us to see whether our participants had enough NOS knowledge to meaningfully engage in rating NOS aspects in terms of developmental appropriateness and importance. However, we did not provide a detailed account of our participants' NOS views for the purpose of this study.

A modified version of Sweeney's (2010) Ideas about Science for Early Elementary (K-4) Students questionnaire coupled with a follow-up interview was used to measure the participants' beliefs about the developmental appropriateness and importance of the target NOS aspects. In each question, after reading the description of one NOS aspect, the respondents were asked to evaluate the developmental appropriateness and importance of this particular NOS aspect and then they were asked to indicate their plans for introducing this NOS aspect in the curriculum for a particular school year. Then participants moved to the next question probing their thoughts about the developmental appropriateness and importance of another NOS aspect.

Three changes were made to Sweeney's (2010) questionnaire in this study. First, participants were asked to rate the developmental appropriateness of the NOS aspects using a scale ranging from *not at all appropriate* (0) to *very appropriate* (4) instead of a *yes* or *no* answer. Second, participants were also asked to provide their reasons why they considered a particular NOS aspect developmentally appropriate and important for the grade level they taught at the time of the study. Third, three items on Sweeney's (2010) questionnaire (i.e., the distinction between scientific laws and theories, the importance of experimentation in science, and the relationship between science and technology) were excluded based on the recommendations from the major science education policy documents (AAAS, 1993; 2009; NRC, 1996; NGSS Lead States, 2013) and NOS literature (Akerson et al., 2011; Akerson & Donnelly, 2010; Quigley et al., 2010) because they were seen as more appropriate for secondary students.

DATA ANALYSIS

We analyzed the data 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).

To answer the research question, first we thoroughly read each participant's questionnaire to create a summary of the participant's conceptions, and beliefs about the developmental appropriateness and importance of the target NOS aspects. We then checked the summary of each participant' conceptions and beliefs against confirmatory or otherwise contradictory evidence in the questionnaire data and modified the summary accordingly. After finishing the explanation building for the questionnaire data, we repeated the same process for the interview transcripts of individual cases. The summaries that were generated from the independent analysis of the questionnaires and interviews were then compared and contrasted to create a final summary of each participant's conceptions and beliefs about the developmental appropriateness and importance of the target NOS aspects. We then searched for initial patterns or categories within the final summary for each participant. We checked the patterns or categories against confirmatory or otherwise contradictory evidence in the data and modified the final summary accordingly. The final summaries of participants' beliefs about the developmental appropriateness and importance of the NOS ideas were compared to identify similarities and differences across cases. Finally, we conducted an iterative process of pattern or category generation, confirmation, and modification many times as needed.

RESULTS

We assessed our participants' NOS conceptions at the end of the professional development program using VNOS-D2 (Lederman & Khishfe, 2002). Our participants' NOS conceptions were not naïve considering the definitions of the nine NOS aspects that were targeted in this study (See Appendix A). All of our participants had necessary background knowledge about NOS to be able to make informed ratings in terms of developmental appropriateness and importance. A detailed account of our participants' NOS knowledge was not provided in this paper because we aimed to explore elementary teachers' perceptions of developmental appropriateness and importance.

In the following section, we first present the individual cases describing each participant's beliefs about the developmental appropriateness and importance of teaching the nine NOS aspects, and then we present the cross-case analysis.

Table 2. The Participants' ratings for the developmental appropriateness and importance of the nine NOS aspects

	Francine		Anna		Nancy		Andy	
NOS aspect	**Appropriate**	**Important**	**Appropriate**	**Important**	**Appropriate**	**Important**	**Appropriate**	**Important**
Inferential	4	4	4	4	4	4	4	3
Creative	4	4	4	4	4	4	4	4
Tentative	4	4	4	4	4	4	4	4
Empirical	4	4	4	4	4	4	4	3
Subjective	4	4	3	3	4	4	3	3
Socio-cultural	4	4	4	4	4	4	4	4
Scientific Methods	3	3	3	3	4	4	3	3
Collaborative	4	4	4	4	4	4	4	3
Bounded	2	2	2	2	4	4	2	2

Note. The numbers in each cell represent the participant's degree of agreement regarding the developmental appropriateness or importance of the corresponding NOS aspect: 0 (not at all appropriate/ important), 1 (slightly appropriate/ important), 2 (neither appropriate/ important nor inappropriate/ unimportant), 3 (somewhat appropriate/ important) or 4 (very appropriate/ important).

Case 1: Francine

Among the nine NOS aspects, Francine raised concerns about the developmental appropriateness and importance of two NOS aspects: the bounded NOS aspect and the absence of step-by-step scientific method.

Francine rated the bounded NOS aspect as the least developmentally appropriate and important NOS aspect among the nine NOS aspects (See Table 2). Accordingly, she did not consider teaching the bounded NOS aspect in her third grade classroom, but she pointed out that she would teach this particular NOS aspect if she were to teach the fifth grade. Francine also modified the NOS poster that we provided by removing the bounded NOS aspect from the poster. The following excerpt captures Francine's thinking about the developmental appropriateness and importance of the bounded NOS aspect for her third grade students.

> We really do not need to teach this [the bounded NOS aspect] in third grade level, especially the part about religion, philosophy, and arts. They are too young to understand like science cannot answer questions about your religion, philosophy or arts. Those terms are more difficult to understand, more abstract…Yes. Science cannot answer all questions. We can teach this part, but if we go to like philosophy and religion, this is not really important or this is not time for those third graders to learn about this [beliefs interview].

Francine thought that her third grade students could understand the general idea that science cannot answer all questions, but they were not ready to learn philosophical, ethical, and religious dimensions of this particular NOS aspect.

As for the absence of a single step-by-step scientific method, Francine rated this particular aspect as *somewhat appropriate/ important* rather than *very appropriate/ important* compared to other NOS aspects, except the bounded NOS aspect (See Table 2). The following excerpt illustrates why Francine rated the absence of a single step-by-step scientific method lower compared to other NOS aspects at the end of the professional development program.

> 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 [beliefs interview].

Even though students' lack of reflections on the absence of a single step-by-step scientific method made Francine question the developmental appropriateness and importance of this particular aspect, she expressed that she would try to teach it again next year. As seen in the following excerpt, Francine believed that she did not have enough evidence to claim that it is totally inappropriate or unimportant 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 author 1: 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 author 1: 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 [beliefs interview].

Contrary to the absence of a single step-by-step scientific method, Francine considered the empirical, inferential, creative, and tentative, subjective, collaborative, and sociocultural NOS aspects *very appropriate* and *very important* to teach at the third grade level (See Table 2). During her interview, Francine expressed that inferential, creative, tentative, and subjective NOS aspects were more obvious to her students during the explicit reflective discussions after each NOS activity. Therefore, she thought that these four NOS aspects were more accessible to her students compared to others. Francine's observations of student learning during NOS lessons caused her to rate these four NOS aspects more favorably in terms of developmental appropriateness and importance.

> When they [students] reflect after each activity the most frequent ones that they were saying were science is based on observation and inference, creative or tentative, and I can also say the subjective [NOS aspect]. These four is the most they were finding. I think that how they reflected changed how I look at these ones… 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 [beliefs interview].

Case 2: Anna

Anna rated three NOS aspects (bounded and subjective NOS aspects, and the absence of a single scientific method) lower than other NOS aspects (See Table 2).

Anna considered the bounded NOS aspect as the least developmentally appropriate and important idea to teach at the fifth grade because she rated only this particular NOS aspect as *neither appropriate nor inappropriate* and *neither important nor unimportant* (See Table 2). As for the developmental appropriateness, Anna stated, "I think it is appropriate because students at this age started to ask about the difference between religion and ethics and science. It is somewhat appropriate because I don't think they are quite old enough to really understand it, yet" [beliefs interview]. She also observed during her NOS teaching that her students made few connections to the bounded NOS aspect when they reflected on the NOS activities. Very few number of students' explicit connections to the bounded NOS aspect during the NOS teaching led Anna perceive this particular NOS aspect less appropriate to teach than other NOS aspects. Moreover, Anna acknowledged that she did not focus on the bounded NOS aspect as much as the other NOS aspects during her NOS teaching. This implies that she did not prioritize teaching the bounded NOS aspect over other NOS aspects. The following excerpt illustrates how Anna approached teaching the bounded NOS aspect.

> I did not do much with it [bounded NOS aspect] 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 [beliefs interview].

Anna rated the absence of a single scientific method *somewhat appropriate* and *somewhat important* to teach at the fifth grade level (See Table 2). She observed during her NOS teaching that her fifth graders could not understand this NOS aspect fully: "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" [beliefs interview]. Anna thought that it was important to convey students the idea about the absence of a single scientific method, but she did not want to give up using the so-called step-by-step scientific method in her science teaching.

In addition to the absence of a single scientific method, Anna also rated the subjective NOS aspect *somewhat appropriate* and *somewhat important* to teach at the fifth grade level (See Table 2). She expressed that some fifth graders would have difficulty in understanding the subjective NOS aspect because they were not developmentally ready to accept that there could be more than one right answer for a given question. Anna's knowledge of her students' varying epistemological sophistication deterred her to rate subjective NOS aspect more favorably. She seemed to suggest that some of her students' dualist personal epistemology might not be conducive for them to develop an informed understanding about the subjective NOS aspect. The following excerpt pictures Anna's thoughts about the developmental appropriateness of the teaching the bounded NOS aspect at the fifth grade.

> It is so hard to explain with these kids. You can describe for them that some scientists think this and others think that because of their own reasons, but some students will say, No, I need to know which one right. I want to know what is right now. It can't be both [beliefs interview].

Unlike the bounded and subjective NOS aspects, and the absence of a single scientific method, Anna rated the empirical, inferential, tentative, creative, collaborative, and sociocultural NOS aspects *very appropriate* and *very important* to teach for her fifth graders (See Table 2). Her justifications for these high ratings varied across the NOS aspects. For instance, Anna thought it is very appropriate and important to teach the tentative and inferential NOS aspects because there were a lot of opportunities in the fifth grade science curriculum to teach these two NOS aspects.

As for the sociocultural NOS aspect, Anna perceived that the diverse nature of the student population in the school which was also reflected in her classroom was conducive to teach this particular NOS aspect. Anna seemed to imply that teaching the sociocultural NOS aspect might not be easy in an elementary school which lacks diversity in the student population.

> I think it is very important to expose them [students] to both men and women scientists in all cultures because we are very diverse school and kids are from everywhere and we need them to know that all this information was collected from all different sorts of people. So, I actually experience it every day in the classroom, you know little bit of it, but it is nice to be able to bring all together and talk about it in science about how people have different ideas because culture and society in which they came from are different [beliefs interview].

The main reason why Anna rated the creative NOS aspect as very appropriate and important to teach was related to her realization that some of her students held misconceptions about this particular NOS aspect. Therefore, she thought that the creative NOS aspect should be explicitly taught to address student misconceptions. Anna observed during her NOS teaching that her students always made references to the creative NOS aspect without giving the necessary attention to the empirical NOS aspect. Therefore, Anna argued that it is very important to explicitly teach that science is creative, but the creativity in science should always adhere to the empirical evidence. She thought that ignoring the relationship between the creative and the empirical NOS aspects might propagate student misconceptions about the creative NOS aspect as seen in the following excerpt.

> Anna: I don't think students understand it [the creative NOS aspect] until we talk about the difference between creativity in science and creativity in art.
>
> The author 1: So, why do you think it is important for them to understand the differences in creativity between science and art?
>
> Anna: I want them to understand that they [students] can't just come up with anything creative out of their head in science and just say this is it, you know. They have to show some evidence. They have to make observations...So, linking the two [creative and empirical NOS aspects] for them, I think, is important [beliefs interview].

Case 3: Nancy

Nancy considered all of the NOS aspects *very appropriate* and *very important* to teach at the fifth grade (See Table 2). During her interview, Nancy explained her high ratings 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" [beliefs interview]. When we conducted our study Nancy was in her first year of both teaching science and teaching the fifth grade. She did not have experience in teaching science and enough time to get to know her fifth grade students' academic strengths and weaknesses so that she could make informed decisions about the developmental appropriateness and importance of NOS aspects: "I don't have much expertise because I have never taught science before. They are all appropriate and important. It is really difficult for me to truly feel like I can rate these [NOS aspects] appropriately" [beliefs interview].

When we further probed Nancy by asking her to rank order these NOS aspects in terms of developmental appropriateness and importance, she listed the creative and inferential NOS aspects as the most appropriate and important NOS aspects while she considered the collaborative and bounded NOS aspects as the least appropriate and important. The reason why Nancy prioritized the creative and inferential NOS aspects was related to her observations of students during NOS teaching. She realized that these two NOS aspects were more accessible for fifth graders because Nancy observed that these NOS aspects were more obvious to her students during the explicit reflective discussions after each NOS activity. During her interview, Nancy explained the reasons why she ranked the collaborative and bounded NOS aspects as the least appropriate and important NOS aspects to teach as seen in the following excerpt.

> I think that there is not as much to explore with those [the collaborative and bounded NOS aspects]. I think they can identify them and we can talk about how, you know, they are true, but I think that they are not always going to be a super important aspect. In fact, in a lot of the activities that we did you wouldn't even have number nine [the bounded NOS aspect] or eight [the collaborative NOS aspect]. Those don't seem to really, you know, always relatable with what kind of things we were doing [beliefs interview].

In addition to her classroom observation, Nancy's relatively lower understanding of the bounded NOS aspect compared to other NOS aspects seemed to influence her ranking of this particular NOS aspect. Nancy stated, "I think that [bounded NOS aspect] 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 is still just a little bit hazy for me" [beliefs interview]. In other words, the fact that she was not able to develop an understanding of the bounded NOS aspect as robust as other NOS aspects made Nancy question the developmental appropriateness of this particular NOS aspect for her fifth graders.

The importance of having sufficient knowledge about NOS also surfaced when she assessed the creative NOS aspect in terms of developmental appropriateness and importance. Unlike the bounded NOS aspect, Nancy ranked the creative NOS aspect as the most appropriate and important because she perceived that she had more robust understanding of the creative NOS aspect after the professional development program. In addition to the role of knowledge in her ranking of the creative NOS aspect, another reason why Nancy considered the creative NOS aspect as the most appropriate and important NOS aspect was related to her poor science learning experience as a student. During her interview, Nancy blamed her lack of interest in science as a student on the lack of explicit exposure to the creative side of science in her prior science learning. After having realized the potential of teaching the creative NOS aspect in drawing students into science, she perceived the creative NOS aspect as the most important NOS aspect.

Case 4: Andy

Andy considered that all of the NOS aspects were appropriate and important to introduce at the fifth grade. However, he thought that some of the NOS aspects were relatively less appropriate and important to teach (See Table 2).

Andy expressed some concerns about the bounded NOS aspect in terms of both developmental appropriateness and importance. He rated the bounded NOS aspect as *neither appropriate nor inappropriate* and *neither important nor unimportant* to teach at the fifth grade because he stated on his questionnaire that it was a higher-level concept for most of his students. During his interview, Andy also expressed "it [NOS teaching] 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 in his classroom understood this particular NOS aspect at the face value. Andy pointed out that students could understand that science cannot answer all questions, but only a few of them could explain why that was the case by providing examples of what kinds of questions science cannot answer.

Another NOS aspect about which Andy raised some concerns regarding the developmental appropriateness and importance was the subjective NOS aspects. He thought that not all fifth graders could understand the subjective NOS aspect because such an understanding requires higher level thinking. Therefore, Andy rated the subjective NOS aspect as *somewhat appropriate* rather than very appropriate (See Table 2). His assessment about the developmental appropriateness of the subjective NOS aspect also led Andy to question the importance of teaching this particular NOS aspect. He expressed that he preferred to spend much of his time on content that all of his students could learn. Therefore, he rated the subjective NOS aspect as *somewhat important* (See Table 2). The following excerpt captures Andy' thinking about the developmental appropriateness and importance of the subjective NOS aspect.

> That [subjective NOS aspect] is a little deeper concept. Science is based on observations and based on all these conclusions. Here is your conclusion based on evidence, but then saying on top of that, oh, but sometimes your conclusions are going to change because you have a personal feeling about it, you know, like that is a little harder concept in general, and I think it is appropriate for fifth graders, but not necessarily every fifth grader because if you are not even getting the basics, it is hard to get the subtext… I would probably say a three [somewhat important] as well because I think that if they are getting it, great. Let's get deeper and say, well, you know, some people differ in their opinion, but if they are not getting the basic idea then why are we even bothering, you know? [beliefs interview].

Similar to the subjective NOS aspect, Andy rated the absence of a single step-by-step scientific method as *somewhat appropriate* and *somewhat important* to teach at the fifth grade (See Table 2). Andy expressed that during his NOS teaching he had a limited opportunity to emphasize the absence of a single step-by-step scientific method and, in turn, he was not able to observe to what extent his students were able to conceptualize this particular NOS aspect. He assessed the developmental appropriateness and importance of the absence of a single step-by-step scientific method by tapping into his prior science teaching experience and/or knowledge about his fifth grade students. Andy thought that his students had been already exposed and understood the idea that there was more than one way to do science. Therefore, Andy rated the absence of a single step-by-step scientific method *somewhat important* to teach. Andy expressed that he did not differentiate the terms of developmental appropriateness and importance in his mind. For this reason, his ratings of this NOS aspect for developmental appropriateness and importance were the same. Andy rated the absence of a single step-by-step scientific method as *somewhat appropriate*. The following excerpt illustrates Andy's thinking about the developmental appropriateness/ importance of teaching the absence of a single step-by-step scientific method.

> Andy: In general, I think it is something that they get. I mean, they get that there is a rule that, you know, there's a way to do things, but at the same time we don't always have to follow that process...So, I would say that it is appropriate. They get it, but I don't think it is that super important they kind of already, I would say, understand that.
>
> The author 1: Why do you think it is important for them to learn that there is no one-way to do science?
>
> Andy: I think the reason is because you don't want them to have this idea that science is a robotic process. That is, you are not really an active participant in, you know. So, if you just think science is this, you know, you just read what the next thing in the book to do is and you do it, you know, just like you are assembling something. This is not just you are just reading a book, what the next step is and you do the next step. It's not like some mindless thing. This is like very engaging, active, and interesting [beliefs interview].

Unlike the three NOS aspects previously mentioned, Andy rated six NOS aspects (i.e., creative, tentative, sociocultural, empirical, inferential, and collaborative) *very appropriate* to teach at the fifth grade (See Table 2) because he thought that fifth grade students could understand these NOS aspects when these NOS aspects were explicitly taught with examples. He thought that his students were in a position to understand the creative, tentative, and sociocultural NOS aspects despite some of them possibly having misconceptions about these NOS aspects. Andy's realization with regard to his students' misconceptions about these three NOS aspects led him to consider these aspects as *very important* to teach. He also thought that the creative, tentative, and sociocultural NOS aspects were not explicitly targeted in his fifth grade students' previous science learning as much as empirical, inferential, and collaborative NOS aspects. Therefore, he considered these three NOS aspects as *very important* so that his students have enough exposure to these *developmentally appropriate* NOS aspects. For instance, the following excerpt represents Andy's thinking about the developmental appropriateness and importance for the sociocultural NOS aspect.

> I think it [sociocultural NOS aspect] is definitely appropriate. They can understand this idea when presented with examples of it, and I also put it at a four for importance [very important] because they don't have a lot of experience sometimes hearing all these different perspectives or they don't get that. We were watching something the other day, and it was like they didn't accept her ideas because she was a woman. They were not viewed as that equally valid. Living in a modern society where we kind of take certain things for granted. So, I think that that is very important for them to see because I think a lot of times they see that you can become famous by being in science because I think they know that is pretty obvious, but I think that they don't get the riskiness of it or that you have to sometimes pushing the boundaries of society or what is acceptable. They just see it as you could, you know, become famous if you are the one who discovers this thing that your name will be in this book, you know, in the future [beliefs interview].

Andy observed that his students thought that new scientific knowledge was always accepted by society without any resistance. Therefore, he felt a need to address this misconception by teaching the developmentally appropriate sociocultural NOS in his view.

Among the six NOS aspects, Andy rated the empirical, inferential, and collaborative NOS aspects as *somewhat important* even though he considered these three NOS aspects as *very appropriate* to teach. Andy thought that his fifth grade students' had more exposure to these three NOS aspects in their previous science learning. Therefore, he lowered the importance of these three NOS aspects to give the priority to the less frequently taught developmentally appropriate NOS aspects such as creative, tentative, and sociocultural NOS aspects.

> I think I probably said it was a three [somewhat important] because I think that it is important, but at the same time you wouldn't teach a child who already understands it [inferential NOS aspect]. I would say this is one of those things that I think they already get it, and they're going to see enough in their work where they don't need to have that explicitly explained to them again. I would say it is definitely appropriate. It is definitely within their grasp, and I would say it is not as important because I think they get it already [beliefs interview].

Cross case analysis

The cross-case analysis showed that the perceived appropriateness and importance of a target NOS aspect were inextricably linked in our participants' minds. More specifically, our participants sometimes made decisions about the developmental appropriateness of a particular NOS aspect based on their thoughts to what extent that NOS aspect was important to teach for their students.

The cross-case analysis also showed that our participants considered each NOS aspect developmentally appropriate and important enough to be introduced at the elementary level. However, some of the NOS aspects were relatively less appropriate or important to teach.

One of the NOS aspects that our participants questioned the developmental appropriateness and importance was the bounded NOS aspect. They deemed the bounded NOS aspect as the least developmentally appropriate and important NOS aspect. All our participants thought that elementary students could understand that science cannot answer all questions, but the students would have difficulty in understanding why science cannot answer moral, ethical, religious, or philosophical questions. Our participants emphasized that these terms might be too abstract for elementary students to understand and examples that could be used to explain these terms were beyond elementary students' understanding. Therefore, they perceived that this particular NOS aspect was not very appropriate and important to teach compared to other NOS aspects. However, they did not consider the bounded NOS aspect as totally inappropriate and unimportant to exclude from elementary classrooms.

Another NOS aspect that three out of four participants questioned in terms of the developmental appropriateness and importance was the absence of a single step-by-step scientific method. All of our participants understood that there is not a single step-by-step scientific method in science, but they did not want to give up using the so-called scientific method in their science teaching. They 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 not a step-by-step scientific method at elementary grade levels would propagate another student misconception by making students think that anything goes in science. Therefore, our participants suggested introducing the misconceived the notion of the scientific method as a starting point and then revising it with a more contemporary understanding that there is more than one way to do science.

The cross-case analysis revealed that our participants used the following criteria separately or in some combination when they were asked to rate NOS aspects in terms of developmental appropriateness and importance: (a) teachers' NOS learning experience, (b) NOS teaching experience, (c) knowledge of their students, (d) knowledge of curriculum, (e) knowledge of school context, and (f) perceptions about the utility value of a NOS aspect or a myth about a NOS aspect. However, this does not mean that all four participants used every single criterion when they were rating NOS aspects in terms of developmental appropriateness and importance.

One of the criteria that our participants used to determine the developmental appropriateness and importance of a particular NOS aspect was their perceptions about the ease of their own learning about that NOS aspect. For example, Nancy experienced a difficulty in improving her bounded NOS views. Therefore, she thought that her students would also face the same difficulty. Her difficulty in understanding the bounded NOS aspect led her to rate this NOS aspect as *the least appropriate.*

Moreover, our participants in many instances used their NOS teaching as a basis for making decisions about the developmental appropriateness and importance of the NOS aspects. For instance, if they observed positive student-learning outcomes with regard to a specific NOS aspect during their NOS teaching then they mostly perceived that NOS aspect as developmentally appropriate/ important. In a similar vein, our participants generally considered a particular NOS aspect as not very appropriate or important when they saw that their students faced some difficulty in learning that NOS aspect.

Our participants also made decisions about the developmental appropriateness and importance of the NOS aspects based on their perceptions of students' cognitive and epistemological developmental levels, and misconceptions about NOS. They thought that students at the elementary level were capable of learning "science cannot answer all questions", but philosophical, moral, and ethical aspects of the bounded NOS aspect should be introduced after the elementary grades. One of the participants (Anna) also thought that students' dualist personal epistemology might hinder their learning about the subjective NOS aspect. When our participants (Anna and Andy) realized that their students held a misconception about a particular NOS aspect they wanted to give priority to this NOS aspect to address the misconception.

Our participants also judged the developmental appropriateness and importance of the NOS aspects by considering to what extent a particular NOS aspect can be embedded within their science curriculum. When a teacher perceived that they could easily integrate a particular NOS aspect he/she rated this particular NOS aspect more favorably.

Yet another criterion that our participants utilized when they rated the NOS aspects in terms of developmental appropriateness and importance was their consideration of the school context. The school had a diverse student population and this diversity was acknowledged and valued by the school administration and our participants. All of our participants perceived that the diversity in their students' backgrounds could be used as an asset when addressing the sociocultural NOS aspect. They thought that they could tap into their students' sociocultural resources when they were explicitly addressing the sociocultural NOS aspect. This contextual connection led all of our participants to rate the sociocultural NOS aspect as *very appropriate* and *very important* to teach. Another example related to the influence of school context on participants' ratings was related to the absence of a single step-by-step scientific method. The school administration required all of the teachers to participate in a regional science fair competition. Our participants perceived that to a certain extent their students' success in the science fair competition was related to their students' application of the so-called scientific method in preparing science fair projects. Even though they all knew that the existence of a single step-by-step scientific method is a myth, they still wanted to teach the so-called scientific method. Therefore, they did not rate the absence of a single step-by-step scientific method as *very appropriate* and *important* to teach.

The last criterion on which our participants based their ratings of developmental appropriateness and importance was their perception of the utility value for a particular NOS aspect or myth. For instance, Nancy thought that she would have developed an interest in science if the creative aspects of science were made explicit to her during her early science learning. This realization for the potential utility value of teaching the creative NOS in increasing students' interest in science led Nancy rate this particular NOS aspect as *the most important* NOS aspect to teach in her fifth grade classroom.

DISCUSSION AND IMPLICATIONS

The present study explored four elementary teachers' perceptions about the developmental appropriateness and importance of the nine NOS aspects after a professional development program including NOS teaching. The following sections discuss the findings of this study in two parts.

Planting a seed for each nos aspect at the elementary level

One of the major findings in this study was that all of the participating elementary teachers considered the nine NOS aspects developmentally appropriate and important to introduce in their science teaching even if their students might not fully develop sophisticated understandings of some NOS aspects. In previous research, Akerson and her colleagues (Akerson et al., 2011; Akerson & Donnelly, 2010; Quigley et al., 2010) generally recommended five to six NOS aspects (i.e., empirical, inferential, tentative, creative, and subjective/ sociocultural) to be included in elementary science teaching. In addition to these NOS aspects, our elementary teachers suggested the inclusion of the bounded NOS, collaborative NOS, and the absence of a single step-by-step scientific method. Similar to Esker and Forawi (2007), we also believe that young students are capable of understanding the NOS content contrary to the commonly held belief that young children should only learn concrete science content excluding NOS. This study has demonstrated that future attempts to improve elementary teachers' and students' understandings of NOS may benefit from targeting all nine NOS aspects without presuming certain NOS aspects are not achievable at the elementary grade levels. Planting a seed for each NOS aspect early at the elementary level can pave the way for elementary students to develop more sophisticated conceptions of these NOS aspects at later grades.

Regardless of their grade level and student backgrounds elementary teachers all agreed that the bounded NOS aspect could/ should be taught at the elementary grade levels by introducing the idea that science cannot answer all questions, while the reasons why science cannot answer moral, ethical, religious, or philosophical questions could/ should be taught after the elementary grade levels. This finding seemed to indicate that teachers suggest a learning progression about the bounded NOS aspect. Teachers should not immediately rule out the teaching of abstract NOS ideas such as bounded NOS. This line of reasoning might be applied when making decisions about whether to teach the relationship between theory and law at the elementary level.

There is a consensus among science education researchers that the relationship between theory and law is not developmentally appropriate to teach at the elementary level (Akerson et al., 2011; Akerson & Donnelly, 2010; Quigley et al., 2010). For this reason, we did not include this NOS aspect in this study. Perhaps, this NOS aspect might be simplified for elementary teachers and students without using the terms theory and law. It might be possible to introduce the ideas that science strives for describing the regularities in nature using math (law) and science looks for explanations for natural phenomena (theory). These NOS ideas might be presented without formally introducing the terms theory and law at the elementary level. This approach can be further explored by tapping into the growing body of literature about learning progressions (Alonzo & Gotwals, 2012; Duschl, Maeng, & Sezen, 2011).

All of our teachers also agreed that introducing the idea that there is not a step-by-step scientific method at elementary grade levels would propagate another student misconception that *anything goes in science* (Feyerabend, 1975). Therefore, our participants insisted on introducing the misconceived notion of the scientific method as a starting point and then revising it with a more contemporary understanding that there is more than one way to do science. In doing this, our teachers seem to suggest a learning progression about the absence of a single step-by-step scientific method. We think that science education community in general and NOS research community in particular should discuss the feasibility of such a learning progression.

The aforementioned findings have valuable implications about teaching NOS, especially for elementary teachers and students. Although all NOS aspects could and should be taught at the elementary grade levels, we agree with the teaching trajectory suggested by Akerson and her colleagues (2010) that elementary students should learn more concrete NOS aspects (empirical and inferential NOS aspects) earlier than more abstract NOS aspects (subjective and bounded NOS aspects).

Assessment criteria for the developmental appropriateness and importance of NOS aspects

The second major finding of this study was related to the elementary teachers' utilization of various criteria in making decisions about the developmental appropriateness and importance of the NOS aspects. Teachers explained their decisions about the developmental appropriateness and importance of the NOS aspects by appealing to their own NOS learning experience, observation of students' NOS learning, knowledge of students, knowledge of curriculum, knowledge of school context, and perceptions about the utility value of a NOS aspect.

Teachers' use of their NOS teaching experience as a criterion suggests that knowledge about NOS is necessary but not sufficient for teachers to make meaningful assessments of NOS aspects in terms of developmental appropriateness and importance. Teachers need to observe how NOS learning unfolds in real classroom context in order to make informed decisions about the developmental appropriateness and importance of the NOS aspects. Therefore, teachers should be given opportunities to teach NOS in their own classroom before they engage in rating the developmental appropriateness and importance of NOS aspects. In this regard, our findings challenge the methodological assumption in Sweeney's (2010) study where the respondents were asked to assess the developmental appropriateness and importance of the NOS aspects by just reading brief definitions of the NOS aspects.

Our participants also considered teaching a particular NOS aspect more favorably when they perceived they could easily integrate that NOS aspect within their science curriculum. Our participants' use of their curriculum knowledge as a criterion suggests that considering a particular NOS aspect as cognitive content (Abd-El-Khalick & Lederman, 2000) which is an integral part of science curriculum helped our participants to perceive teaching this NOS aspect as more developmentally appropriate and important. Given that teachers' perceptions about the presence of a particular NOS aspect in the standards might predict its inclusion in the classroom instruction (Sweeney, 2010), this finding implies that teachers are more likely to teach NOS if they perceive that their science curriculum is conducive to include the NOS aspects.

All of our participants reported that they were not explicitly exposed to NOS during their K-12 and higher education. One of them (Nancy) stated that if she was exposed to the NOS conceptions early in her K-12 education she would be more likely to develop interest in science. This finding supports the claim that having an understanding of NOS may develop student interest in science (Lederman, 1999; Meyling, 1997; McComas, Almazroa, & Clough, 1998).

In summary, a holistic examination of the aforementioned criteria seems to underscore the importance of developing pedagogical content knowledge (PCK) for

NOS. The criteria that the teachers used when they rated the NOS aspects in terms of developmental appropriateness and importance have one on one correspondence with certain components of PCK described by Grossman (1990) and Magnusson, Krajcik, and Borko (1999). One of these related PCK components was the *knowledge of students*. This component includes students' understanding, conceptions, and misconceptions of particular topics in a subject matter. Another related PCK component was the *knowledge of curriculum.* This component includes knowledge of relevant instructional materials, knowledge of the subject matter and skills that are being attained by students in other classes, and knowledge of the curriculum for a specific subject across grades. Our participants were tapping into their PCK for NOS when they were asked to rate the NOS aspects.

The limitations of the study

The present study had two limitations. First, the findings of this exploratory study are applicable to the four elementary science teachers who worked at a high achieving school giving a special emphasis on science. Accordingly, the developmental appropriateness and importance of the NOS aspects were determined from data obtained from the four elementary teachers at this school. Considering the interplay between teacher beliefs and context (Mansour, 2009; Nespor, 1985, 1987; Pajares, 1992; Windschitle & Sahl, 2002), the developmental appropriateness and importance of the NOS aspects could be perceived differently by teachers 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 included only one third grade teacher and three fifth grade teachers. Future studies might include teachers who better represent the elementary grade band levels.

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Appendix A: Descriptions of the target nature of science aspects

NOS aspect	Description
Empirical NOS	Scientific knowledge is based on observations of the natural world. These observations are also called evidence, facts, or data.
Inferential NOS	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.
Creative NOS	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.
Subjective NOS	Scientific knowledge is not entirely objective. This means that personal values, prior knowledge and experience affect what scientists study and how they do science.
Tentative NOS	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.
Absence of a Single Step-by-Step Scientific Method	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.
Sociocultural NOS	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.
Collaborative NOS	Scientists may work in teams or work alone, but all communicate with each other, share their knowledge, and critically review each other's work.
Bounded NOS	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.

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.

Appendix B: The list of instructional materials used in the nos training

Instructional Material	The Use of Instructional Material in the NOS training	Reason(s) for Inclusion
Article on the Myths of NOS (McComas, 1998)	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.	To familiarize teachers with contemporary conceptions of NOS To convince teachers about the need for change to address the *personal development* component of Bell and Gilbert's (1996) model.The previous use of the article with teachers (Abd-El-Khalick & Akerson, 2004; Akerson et al., 2006; Morrison et al., 2009)
Bottle	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.	To introduce the target NOS aspects The previous use of *Black-box Activities* with elementary teachers (Abd-El-Khalick & Akerson, 2004; Akerson et al., 2009a; Akerson et al., 2007; Akerson et al., 2006; Donnelly & Argyle, 2011; Koening et al., 2012; Matkins & Bell, 2007; Posnanski, 2010)
Seven Blind Mice (Young, 1992)	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.	To reinforce NOS aspects The use of *Children Literature*, 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)

Appendix B: (Continued)

Instructional Material	The Use of Instructional Material in the NOS training	Reason(s) for Inclusion
What Do You Do With a Tail Like This? (Jenkins & Page, 2003)	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.	The use of *Children Literature*, 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)
Fossils (Lederman & Abd-El-Khalick, 1998)	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.	To reinforce NOS aspects The previous use of the activity with elementary teachers (Matkins & Bell, 2007; Koening et al., 2012)
Tricky Tracks (Lederman & Abd-El-Khalick, 1998)	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.	To reinforce NOS aspects The previous use of the activity with elementary teachers (e.g., Akerson et al., 2000; Akerson et al., 2007; Akerson et al., 2006; Donnelly & Argyle, 2011; Posnanski, 2010)
Tangram (Choi, 2004)	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.	To reinforce NOS aspects
Cube (Lederman & Abd-El-Khalick, 1998)	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.	To reinforce NOS aspects The previous use of black-box activities with elementary teachers (Abd-El-Khalick & Akerson, 2004; Akerson et al., 2009a; Akerson et al., 2007; Akerson et al., 2006; Donnelly & Argyle, 2011; Matkins & Bell, 2007; Koening et al., 2012; Posnanski, 2010)
Article on NOS Teaching Strategies (Akerson et al., 2010)	Teachers read and discuss Akerson and her colleagues' (2010) article on a research-based model and strategies for teaching NOS to young children.	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.
The Analysis of NOS Standards	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	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).
NOS Poster	After each NOS activity, the instructors refer to the NOS poster that includes the definitions of the target NOS aspects	The use of visual aids was suggested by Akerson and her colleagues (2010) to introduce or reinforce NOS aspects for young children.

Appendix B: (Continued)

Instructional Material	The Use of Instructional Material in the NOS training	Reason(s) for Inclusion
Assessment of Elementary Students' NOS Ideas	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	Inspired from the NOS card-exchange activity (Cobern & 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 previous studies (Abd-El-Khalick & 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).