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Elementary teachers' perceptions about the effective features of explicit-reflective nature of science instruction

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ABSTRACT

This qualitative study explored elementary teachers' perceptions about the effective features of explicit-reflective nature of science (NOS) instruction. Our participants were four elementary teachers from a public charter school located in the Southwestern U.S.A. The four elementary teachers participated in an academic year-long professional development about NOS which consisted of NOS training and NOS teaching phases. After each phase of the professional development, we specifically asked our participants which features of the explicit-reflective NOS instruction they found effective in improving their NOS conceptions by presenting pre- and post-profiles of their NOS conceptions. We identified nine features perceived by the participants as effective components of explicit-reflective NOS instruction: (1) specific focus on NOS content, (2) participation in hands-on NOS activities, (3) introductory NOS readings, (4) multiple types/forms of reflection, (5) multiple exposure to NOS content, (6) structural consistency in the presentation of NOS content, (7) the evaluation of secondary NOS data from elementary students, (8) the analysis of national and state science standards in terms of NOS content, and (9) NOS teaching experience.

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Since the late 1950s, developing the scientific literacy (also commonly referred to as science literacy) of students has been widely claimed to be a desired outcome of science education (DeBoer, 2000). In this regard, understanding of nature of science (NOS) has been considered an important part of the scientific literacy, and hence, teaching NOS has been supported at K–12 education by major science education policy documents in the U.S.A. (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996; NGSS Lead States, 2013).

NOS refers to values and beliefs specific to scientific knowledge and its development (Lederman, 1992, 2007). More specifically, NOS addresses issues such as 'what science is, how it works, the epistemological and ontological foundations of science, how scientists operate as a social group and how society itself both influences and reacts to scientific endeavors' (Clough, 2006, p. 463). There is no agreed-upon single definition of NOS among philosophers of science, historians of science, scientists, and science educators,

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but certain NOS conceptions are not controversial and germane to K–12 education (Lederman, 2007). These NOS conceptions include, but are not limited to, conceptions that scientific knowledge is empirically based, tentative, subjective, inferential, and socially and culturally embedded, and depends upon human creativity and imagination.

Based on the literature on the attempts undertaken to improve students' or teachers' conceptions of NOS, two distinct instructional approaches can be identified: (a) the implicit approach and (b) the explicit-reflective approach (Lederman, 2007).

Implicit approach

Some researchers (e.g. Barab & Hay, 2001; Bell, Blair, Crawford, & Lederman, 2003; Richmond & Kurth, 1999; Ritchie & Rigano, 1996; Ryder, Leach, & Driver, 1999; Salter & Atkins, 2013) attempted to examine the impact of the implicit approach on students' or teachers' NOS conceptions through engaging them in scientific inquiry activities, science content coursework, or doing science in authentic laboratory settings.

Barab and Hay (2001) and Richmond and Kurth (1999) reported gains in students' conceptions of NOS as a result of 8- to 10-week research experience without doing formal NOS assessments. In a more recent study with undergraduates who plan on becoming elementary teachers, Salter and Atkins (2013) also immersed preservice teachers in authentic inquiry so that they would deepen their NOS conceptions and improve their attitudes towards science. As a result of 15-week research experience, the researchers claimed that preservice teachers' NOS conceptions have improved based on interviews with the preservice teachers and their written reflections on the study intervention. However, the researchers reported that they were not able to detect similar improvements through pre- and post-administration of Views About Sciences Survey (VASS) and Mathematics and Science Teacher Education Program (MASTEP) survey. Although Ritchie and Rigano (1996) reported that participants developed into independent researchers, they did not comment on gains in students' conceptions of NOS as a result of the research experience. Ryder et al. (1999) reported limited gains in undergraduates' understanding of NOS as a result of eight-month authentic research experience.

In contrast to the positive findings of Barab and Hay (2001), Richmond and Kurth (1999), and Salter and Atkins (2013), Bell et al. (2003) reported that eight-week research experience did not make any difference in students' conceptions of NOS based on formal NOS assessments. Only Bell et al. (2003) used formal NOS assessments. Except for the study of Ryder et al. (1999), all of these studies suffer from similar shortcomings. Students were placed into an apprenticeship programme under the mentorship of a scientist for a 7- to 10-week period in all of these studies. Students became part of a research team and engaged in different aspects of the scientific inquiry. Students found themselves in the midst of an ongoing research project and they tried to keep up with the pace of the project. They had an extremely limited amount of control over the research agenda. In general, the actual contact time between the students and their mentor was not mentioned or this contact time was short (e.g. five hours a week). Learning the culture and practice of science through participation in scientific communities of practice takes time and it is unreasonable to expect major gains in students' understanding of culture and practice of science within 7- to 10-week periods.

The critical review of these studies suggests that learners' NOS views without deliberately teaching the target NOS aspects will be likely to remain naïve and will not suffice to qualify as informed even if the amount of time spent in authentic research settings is increased. These studies revealed that engaging a large number of learners in doing science in an authentic laboratory environment was not an easy task to achieve and learners' conceptions of NOS were not found to be significantly improved by their short-term involvement in authentic science settings (e.g. Bell et al., 2003).

The implicit approach to teach NOS was also undermined by some studies, indicating that even the scientists do not necessarily hold contemporary NOS conceptions with regard to every single NOS aspect (e.g. Glasson & Bentley, 2000; Pomeroy, 1993; Wong & Hodson, 2009). As Clough (2006) pointed out, 'expecting students to generate, on their own, accepted science and NOS ideas does an injustice to fields of study in which brilliant minds have struggled for decades, even centuries, to arrive at our current understandings' (p. 467). Moreover, such expectation that students will abandon their prior thinking and construct accurate NOS views simply by engaging in scientific inquiry activities also reflects naive views of how people learn (Clough, 2006).

Explicit-reflective approach

A considerable number of studies have examined the impact of explicit-reflective NOS instruction on students' or teachers' NOS conceptions (e.g. Abd-El-Khalick, 2001; Abd-El-Khalick & Akerson, 2004, 2009; Akerson, Abd-El-Khalick, & Lederman, 2000; Akerson, Morrison, & McDuffie, 2006; Khishfe & Abd-El-Khalick, 2002; Palmquist & Finley, 1997; Schwartz, Lederman, & Crawford, 2004). An *explicit* approach to teaching NOS, used in these studies, should not be confused with traditional didactic instructional approaches. Explicit instruction purposefully makes NOS aspects visible to learners by drawing their attention to relevant NOS aspects through discussion and questioning. The *reflective* part of the explicit-reflective NOS instruction, on the other hand, refers to encouraging learners to revise their NOS ideas in light of new ideas they encounter about NOS.

Studies which employed explicit-reflective NOS instruction came to the same conclusion that the explicit-reflective approach was overall effective in improving NOS views across different contexts. The explicit approach was effective within the context of a physics course designed for elementary teachers (Abd-El-Khalick, 2001), an elementary science teaching methods course (Abd-El-Khalick & Akerson, 2004, 2009; Akerson et al., 2000, 2006), a sixth-grade science class (Khishfe & Abd-El-Khalick, 2002), a secondary science methods course (Palmquist & Finley, 1997), and an authentic research experience (Schwartz et al., 2004). In addition to research studies, major literature review papers about NOS (Abd-El-Khalick & Lederman, 2000; Lederman, 1992, 2007) also reached the same conclusion that the explicit-reflective approach is more effective in improving students' and teachers' NOS conceptions compared to the implicit approach.

Even though the explicit-reflective approach has been shown to be more effective than the implicit approach, the review of the corresponding literature indicates that the explicit-reflective approach can vary in effectiveness. For instance, Khishfe and Lederman (2007) showed that content-independent explicit-reflective NOS instruction was as effective as content-embedded explicit-reflective NOS instruction in promoting adequate views of

NOS. Yet, Melville (2011) found that the explicit-reflective approach could be more effective when it was combined with both content-embedded instruction and content-generic NOS activities. In other words, it was well documented in the corresponding literature that explicitness and reflection are two important features of effective NOS instruction. However, researchers show some levels of disagreement regarding whether, and in what context, integrating the explicit-reflective NOS instruction into science content promotes NOS conceptions consistent with science education reform documents. In this regard, there is a need for further studies that examine how to increase the effectiveness of the explicit-reflective NOS instruction.

One of the major limitations in the existing literature on NOS is that the majority of studies (e.g. Abd-El-Khalick, 2001; Akerson et al., 2000; Akerson, Hanson, & Cullen, 2007; Celik & Bayrakceken, 2012; Dass, 2005; Koenig, Schen, & Bao, 2012; Matkins & Bell, 2007; Salter & Atkins, 2013) that identified effective instructional approaches stressed the significance of uninformed NOS views at the onset of the study and informed NOS views at the conclusion of the study, but they do not provide much insight as to which features of the given intervention were effective in improving the participants' NOS conceptions. In this regard, we found a few studies (McDonald, 2010; Morrison, Raab, & Ingram, 2009; Schwartz et al., 2004) that focused on investigating which features of the explicit-reflective instruction are perceived as effective by students and teachers. Therefore, this paper aims to explore the effective features of the explicit-reflective NOS teaching as perceived by the elementary teachers who participated in a professional development programme about NOS, which lasted for an academic year.

Schwartz et al. (2004) investigated secondary preservice science teachers' NOS learning gains and what factors contributed to the development of participants' NOS views during a science research internship course. They found that 11, out of 13, preservice teachers showed advancements in their NOS views and they reported 3 factors contributing to participants' NOS learning gains: active reflection on NOS ideas, context for reflection, and participants' disposition towards reflection. They defined *active reflection* as being purposeful and explicit, which allows peer support and sharing. As they acknowledged, what they defined as *active reflection* corroborates with what is known as the explicit-reflective approach to teach NOS in the literature. In other words, explicit opportunities for reflection through the journals and discussions were influential for developing the interns' NOS views. Schwartz et al. also concluded that the scientific inquiry context, in this case the interns' experience in the research setting, provided a conducive environment for participants to reflect on their NOS views. They found that participants' disposition towards reflection was another factor influencing the development of participants' NOS views. Participants who were more inclined to reflection on their authentic research experience from a NOS perspective were more likely to develop their NOS views.

Morrison et al. (2009) investigated how elementary and secondary teachers' views of NOS and their views of scientists were affected by inquiry-based professional development experience. They also examined how daily interactions with a scientist focusing on NOS influenced elementary and secondary teachers' views of NOS and their ideas regarding teaching science. The implemented intervention included explicit-reflective NOS activities, combined with one full day of shadowing a scientist without engaging in authentic scientific research, interviewing a scientist along with written and oral reflections, discussion of two videos addressing history of science, participating in inquiry-based activities, developing inquiry-based unit plans, developing four inquiry-based activities, daily reflection papers, and a final course reflection paper. Morrison et al. found that elementary and middle-level teachers who did not hold a science degree mentioned in interviews or written reflections that interviewing a scientist, job shadowing, or simply having informal lunch-time conversations with scientists helped them to improve their NOS views. Secondary teachers who had undergraduate or graduate degree in science and had taught high school science perceived that their NOS views were reaffirmed or validated rather than significantly changed. These secondary teachers added that job shadowing experience or an interview with a scientist helped them to gain new insights about teaching their students about NOS. These findings suggest that the effective feature of the given course show some changes with respect to whether participants are elementary or secondary teachers due to their levels of previous experiences with scientists or research science.

McDonald (2010) investigated the influence of a science content course combining explicit NOS and argumentation instruction on five preservice primary teachers' NOS views. She examined the changes in preservice teachers' NOS views, the influence of the course components on their NOS views, and the factors mediating the development of their NOS views. McDonald investigated to what extent preservice teachers found the following course components as effective in improving their NOS views: (a) explicit NOS instruction, (b) explicit argumentation instruction, (c) argumentation scenarios, (d) global warming task, (e) superconductors survey, and (f) laboratory project. She found that none of the preservice teachers made an explicit reference to the inquiry-based laboratory project as a course component influencing their views of NOS. On the other hand, a few preservice teachers considered explicit NOS activities and explicit argumentation instruction as components influencing their NOS views and most preservice teachers referred to argumentation scenarios, global warming task, and superconductors survey as contexts to learn about certain NOS aspects. Unexpectedly, three of the preservice teachers made an explicit reference to classroom discussions when asked to recall any specific aspects or instances of NOS in the course. These findings suggest that participant preservice teachers did not perceive all course components as effective in improving their NOS views.

Another limitation of the literature is that studies using the explicit-reflective NOS intervention did not tap into the professional development literature with some exceptions (e.g. Akerson, Cullen, & Hanson, 2009; Akerson & Hanuscin, 2007). Therefore, the present study aimed to explore elementary teachers' perceptions about the effective features of the explicit-reflective NOS instruction by making use of the literature about both NOS, particularly for elementary teachers (e.g. Akerson et al., 2000, 2007; Akerson, Cullen, et al., 2009; Akerson, Townsend, et al., 2009; Morrison et al., 2009; Posnanski, 2010), and teacher professional development (e.g. Birman, Desimone, Porter, & Garet, 2000; Garet, Porter, Desimone, Birman, & Yoon, 2001; Guskey, 1985, 1986, 2002; Yoon, Duncan, Lee, Scarloss, & Shapley, 2007).

Following Guskey's (1985, 1986, 2002) teacher change model, we provided opportunities for our teachers to take what they have learned in the training and apply their learning in their own classroom. This approach allowed our teachers to assess the efficacy of their newly learned NOS ideas from the professional development in actual classroom settings. If the teachers see any cognitive or affective improvements in their students' NOS learning, this would result in positive changes in their beliefs about, and attitudes towards, NOS and NOS teaching. In other words, we conceptualised NOS teaching as an integral part of professional development rather than as a follow-up to professional development (Akerson, Cullen, et al., 2009).

The professional development programme implemented in the present study was also guided by Birman et al.'s (2000) three structural features (*form*, *duration*, and *participation*) and three core features (*content focus*, *active learning*, and *coherence*) suggested for effective professional development. As for the *form* feature of effective professional development (Birman et al., 2000), we structured our professional development programme using a reform format rather than traditional approaches such as one-shot workshops or institutes. As for the structural feature of *duration* (Birman et al., 2000), we distributed or sustained the professional development activities over time (Garet et al., 2001), namely one academic year. Moreover, we organised an hour long, 14 face-to-face teacher meetings regarding NOS and NOS teaching, and at least 4 NOS teaching practices in participating teachers' classrooms. Considering Yoon et al.'s (2007) findings, we intentionally wanted to provide at least 14 hours of professional development dispersed throughout one academic year. Yoon et al. (2007) reported that studies providing 5–14 hours of professional development showed no statistically significant effects on student achievement. As for the structural feature of *participation* (Birman et al., 2000), we organised professional development for groups of teachers from the same school rather than targeting in-service programmes towards individual teachers (Garet et al., 2001).

As for the *content focus* core feature of effective professional development (Birman et al., 2000), we focused on improving and deepening elementary teachers' content knowledge about NOS and, to a lesser degree, their knowledge about how students learn NOS. Teachers' *active learning* as highlighted by Birman et al. (2000) took a number of forms in our professional development programme. These forms included the opportunity to (a) observe and participate in several NOS lessons, (b) test some of these NOS lessons in their classrooms, (c) examine and assess examples of students' responses about NOS, (d) discuss how to revise NOS activities for their students, and (e) collectively reflect on how NOS lessons worked in their classrooms. To promote the *coherence* core feature of effective professional development (Birman et al., 2000), we included activities providing teachers the opportunity to (a) examine and review national and state science standards in terms of NOS, (b) individually and collectively identify relevant NOS aspects presented in each activity, (c) discuss the extent to which NOS activities were appropriate for their students, (d) share ideas about how to adapt NOS activities for their students, and (e) test and reflect on their NOS classroom teaching.

Methodology

Participants

We started the study with eight teachers at an elementary school in the Southwest region of the U.S.A. Only four elementary teachers showed their commitment to complete all phases of the professional development programme. Therefore, we only included the views of these four teachers to get a holistic view about the effective features of NOS instruction, which lasted for an academic year. These four elementary teachers did not receive any college credit or monetary compensation for their participation, unlike previous studies (e.g. Akerson et al., 2007; Akerson, Cullen, et al., 2009; Deniz & Adibelli, 2015; Posnanski, 2010). They participated in the study because they felt a genuine need to improve their NOS understanding and pedagogical knowledge about NOS. The following paragraphs provide more information about each of these four elementary teachers.

Francine was the only third-grade teacher. She was 36 years old. Francine was the only teacher whose first language was not English. She completed her undergraduate education in Turkey. Throughout her undergraduate years, Francine took only three science content courses. She was certified to teach K–8 grades in the U.S.A. and she also had a master's degree in Gifted Education from an American university. Francine had been teaching science at the third-grade level for five years. She expressed that on average she spent four to five hours on teaching science each week.

Anna was a fifth-grade teacher at the school. She was a 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 on average spent four to five hours on teaching science each week.

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 coming to 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 our professional development programme. She was a 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 should spend teaching science in her classrooms, yet she planned to teach at least two hours of science each week.

Andy was another fifth-grade teacher at the school. 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 four to five hours on teaching science each week.

The school context

Our participants worked at a school located in the Southwest region of the U.S.A. The school is a K–12 state-sponsored tuition-free public charter school with Science, Technology, Engineering, and Mathematics (STEM) emphasis. The selection of the school was based on its convenience. First, we had personal connections with the administrators and teachers at this school because we voluntarily served as judges in the school 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 personal rapport with the school personnel and the school's emphasis on STEM education created a very conducive environment to recruit teachers for NOS professional development without offering any compensation.

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 are a limited number of research studies (e.g. Akerson & Hanuscin, 2007; Akerson, Cullen, et al., 2009) that provided a professional development programme for this particular grade band.

Professional development programme

Our professional development programme consisted of two phases: NOS training and NOS teaching. The first phase (NOS training), which took about six months, aimed to improve participants' understandings of NOS and NOS teaching. We organised a total of 14 face-to-face meetings during NOS training. (See Appendix 1 for the list of instructional materials used in NOS training and Appendix 2 for the NOS poster specifically designed for this study.) During the last meeting of the first phase, our participants also worked on revising NOS activities that they planned to teach in their classrooms during the second phase of the professional development programme. The second phase (NOS teaching), which took about one month, provided opportunities for our participants to practise teaching NOS in their own classrooms. During the NOS teaching phase of the professional development programme, our participants taught at least four NOS lessons in their classrooms. Moreover, we organised a face-to-face meeting to collectively reflect on our participants' NOS teaching and their students' subsequent NOS learning.

NOS training provided in the first phase of our professional development programme was developed around the explicit-reflective instructional approach. We started NOS training with the Bottle activity by using explicit-reflective instruction in which the elementary teachers' participation in the activity was followed by the authors' intentional attempts to connect NOS aspects to the salient parts of the activity. We used the NOS poster (Appendix 2) and the definition list for NOS aspects as visual aids when we connected NOS aspects to the NOS activity. This first NOS activity allowed us to realise 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 NOS activity in their classroom. (See Appendix 3 for the structured reflection worksheet designed for one of the NOS training activities.)

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

Data collection

We used the Views of Nature of Science Questionnaire-Form VNOS-D2 (Views of Nature of Science Elementary School Version 2; Lederman & Khishfe, 2002) coupled with follow-up interviews at the beginning of NOS training, at the end of NOS training, and at the end of NOS teaching. At the end of NOS training and at the end of NOS teaching, the first author provided the elementary teachers with their written NOS responses and asked them specifically to compare and contrast their pre- and post-NOS training, and post-NOS teaching responses in the questionnaire. If the participants perceived any improvements in their responses to the questions, the first author followed up by asking whether this perceived improvement could be attributed to the professional development programme, and if so, which features of the professional development programme they perceived effective in improving their NOS understandings. The administration of the NOS instrument also allowed us to check whether our participants had indeed improved their NOS conceptions. Finally, the first author also took field notes throughout the professional development programme, videotaped the face-to-face meetings done in the professional development programme, and collected the professional development artifacts to triangulate questionnaire and interview data.

Data analysis

Our qualitative data analysis followed a protocol similar to that described by Tobin (2000) for interpretive research. First, the researchers read thoroughly each participant's questionnaire to generate a summary of the participant's conceptions regarding 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 interview data and modified accordingly. The process of pattern or category generation, confirmation, and modification was conducted many times as needed. The same process was repeated with the corresponding questionnaires and interviews to generate pre-teaching and post-teaching profiles. Second, pre-instruction, pre-teaching, and post-teaching profiles were compared to note whether, or what types of, changes occurred in the participants' NOS conceptions and what changes were perceived by the participants in relation to the professional development components. Third, the identified patterns were compared and contrasted across the participants to identify what types of changes were commonly observed in the participants' NOS conceptions and which feature(s) of the professional development programme were commonly found valuable in changing their NOS conceptions.

The quality of research

We followed Yin's (2003) four tests to ensure the quality of this qualitative study: (a) construct validity, (b) internal validity, (c) external validity, and (d) reliability. We used *the multiple sources of evidence* for construct validity (Yin, 2003). In this study, audiotaped semi-structured interviews were used to corroborate the written responses on the questionnaires and information from other sources such as videotapes of the meetings, the researcher's field notes, and the professional development artifacts. With the use of *the multiple sources of evidence*, we also achieved *data triangulation* by Denzin (1984) and Patton (1987) because *the multiple sources of evidence* allowed the researchers to measure the same phenomenon in different contexts and looked for whether they remained the same or not.

To ensure the internal validity, we used the analytic tactics of *pattern matching* and *explanation building* (Yin, 2003) and clarified the researcher's bias (Creswell, 2007; Merriam, 1998). Particularly, we looked for coinciding patterns from each participant, and developed a general explanation about the case, with respect to the types of changes that occurred in the participant's NOS conceptions and the features of the professional development programme perceived by the participant as effective in improving his or her NOS conceptions. To reduce the researchers' biases about the effectiveness of the explicit-reflective NOS instruction, the first author asked explicitly to the participants whether they perceived any change in their NOS conceptions and whether this change could be attributed to their participation in the professional development programme.

In the present study, we used *multiple cases* (Yin, 2003) and provided *thick description* (Lincoln & Guba, 1999) to ensure external validity. Reaching common conclusions from multiple cases (i.e. four teachers in our study) implies that findings have the possibility of direct replication (Yin, 2003). Based on the review of the literature on NOS learning of teachers, we provided detailed information about the relevant characteristics of each participant in the methodology section and 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 are applicable in his or her own situation.

To ensure reliability, we used *inter-coder agreement* (Creswell, 2007) and created *a case study database* (Yin, 2003). In the process of *inter-coder agreement*, the researchers first separately and then together analysed the data from two participants by following the aforementioned data analysis procedure. Disagreements were handled by appealing to the data and through discussions. The researchers reached 100% agreement at the end. In addition, we created a database in which we put both the raw data and our reports by creating a folder system on the computer (Yin, 2003). Such organisation of the data in various folders and subfolders can enable other investigators to inspect the raw data that led to the study's conclusions (Yin, 2003).

Findings

In the present study, we investigated which features of the professional development programme the participants perceived contributed to the development of their NOS conceptions. The data obtained from the participants' post-NOS training and post-NOS teaching questionnaires and interviews and the first author's field notes were examined to identify the features of the professional development programme that the participants found effective in improving their NOS conceptions. We identified nine features perceived by the participants as effective characteristics of the explicit-reflective NOS instruction.

Before providing detailed information about the perceived effective feature of NOS instruction, it would be helpful to provide evidence indicating that NOS instruction was actually effective in improving our participants' NOS conceptions. Thus, the findings of this study are presented in two sections. The first section aims to present the changes in our participants' NOS conceptions after their participation in the explicit-reflective NOS instruction. The second section aims to explain the nine effective features of NOS instruction perceived by our participants.

Effectiveness of NOS instruction

Our analysis revealed that four NOS aspects (i.e. empirical, tentative, creative, and subjective) consistently appeared in all of our participants' pre- and post-NOS questionnaire and interview data. Inferential, bounded, social, and sociocultural NOS aspects and the absence of the scientific method, on the other hand, did not appear in all of our participants' pre- or post-NOS data. Thus, the findings about the effectiveness of NOS instruction are presented and explained in two sections. The first section describes conceptual changes in commonly observed four NOS aspects (i.e. empirical, tentative, creative, and subjective NOS aspects). The second section explains conceptual changes in relatively less observed NOS aspects (i.e. inferential, bounded, social, and sociocultural NOS aspects and the absence of the scientific method).

Empirical, tentative, creative, and subjective NOS aspects

At the beginning of the professional development programme, all of our participants thought that science is empirically based, tentative, creative, and subjective. However, they showed varied degrees of sophistication in their NOS conceptions across these four NOS aspects. Compared to the other three participants, Andy had more consistent and sophisticated NOS conceptions across these four NOS aspects at the beginning of the professional development programme because only he was able to provide an example for, or elaborate on, his NOS conceptions. For instance, at the beginning of the professional development programme, Francine provided a simple answer to the question of whether scientific theories could change by stating, 'I think it might change, but I am not sure' (pre-NOS questionnaire). Anna, on the other hand, believed that when scientific knowledge was supported with experimental evidence, it becomes certain. Thus, she thought only scientific knowledge that cannot be 'proven' with experimental evidence could change with the availability of new evidence and technology. 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. Unlike the other three participants, Andy was able to explain different ways of changing scientific knowledge with an appropriate example. During the pre-NOS interview, Andy expressed that theories often change with the availability of new evidence through the use of new technology. However, Andy also explained that scientific knowledge could change with the reinterpretation of old theories from a different perspective as in the Newtonian vs. Einstein understanding of the gravity in the history of science.

At the end of the professional development programme, all of our participants continued to acknowledge the empirical, tentative, creative, and subjective NOS. However, they also elaborated on, or solidified, their NOS conceptions by providing relevant examples from NOS training activities and their NOS teaching experience, or by making connections among NOS aspects. For instance, beyond simply appreciating the tentative NOS, as mentioned above, Francine started to relate the subjective NOS to the tentative NOS after our professional development programme. She made a generalisation across different NOS training activities that scientists might come up with multiple plausible explanations by looking at the same data set. 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)

As for the tentative NOS aspect, Anna started to acknowledge that *all* of scientific knowledge could change. In addition, she realised that not only new information or technology, but also a new way of looking at the existing data might change scientific knowledge.

Nancy, on the other hand, continued to think at the end of the professional development programme 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 scientific knowledge. Like Anna, Nancy also realised that scientific knowledge could also change with the availability of a new perspective on the existing data at the end of the professional development programme.

Andy, unlike the other three participants, continued to explain that scientific knowledge could change not only with new information or technology, but also with new perspective by providing appropriate examples. Although Andy held very similar tentative NOS conceptions at the end of his NOS teaching, he started to refer to NOS training activities or his NOS teaching experience to elaborate on his tentative NOS conceptions. In addition, he started to conceptualise the tentative NOS aspect from a more holistic perspective. During the post-NOS teaching interview, he expressed that teaching the tentative NOS through NOS activities helped his students to view science as a human endeavour 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 this was obvious, this is the next step, of course they are going to figure that out, but when they have that experience, I think it makes it a lot more humanizing for them. 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 a robotic thing that is happening and eventually someone is going to figure that out. 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)

In summary, even Andy who held relatively sophisticated conceptions in the tentative NOS aspect at the beginning showed significant changes after participation in our professional development programme. The type of changes highlighted above in the tentative NOS aspect was also evident in the other commonly observed NOS aspects (empirical, creative, and subjective NOS aspects); however, due to page limitation and not being the main focus of the present paper, they are not presented here in detail.

Inferential, bounded, social, and sociocultural NOS aspects and the absence of the scientific method

Unlike the 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 the inferential NOS conceptions of

Francine, Anna, and Nancy because they thought that they did not have enough science content knowledge to answer the questionnaire question about how scientists determined the structure of an atom. At the beginning of the professional development programme, Andy was able to explain how scientists inferred the structure of an atom using Rutherford's gold foil experiment. However, he sometimes used inappropriate terminology to express his inferential NOS conceptions. Unlike his pre-NOS interview where Andy used the verb 'deduce', on his questionnaire he 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'. At the end of the professional development programme, Andy started to express his inferential NOS conceptions using more appropriate language. He no longer used the term 'prove' in his explanation of how scientists determined 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).

As for the bounded NOS aspect, Andy was the only participant who provided explicit statements at the beginning of the professional development programme. He acknowledged that science cannot answer all types of questions. Andy was able to differentiate between scientific and non-scientific questions by appealing to the existence of empirical evidence during his pre-NOS interview:

> There are some questions science cannot answer. It's hard for science to answer why the universe is here in the first place. That's not really a scientific question. I think science can answer question where you can observe evidence about.

At the end of the professional development programme, Andy seemed to clarify his bounded NOS conceptions. He underscored during his post-NOS interview that now it was easier for him to explain to 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.

At the beginning of the professional development programme, 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. At the end of the professional development programme, Nancy held very similar conceptions with respect to the social NOS aspect. She continued to believe that scientists may work in teams or alone, but her NOS conceptions became more concrete after the professional development programme because she 'saw them in action'.

At the beginning of the professional development programme, only Francine and Andy provided statements indicating their conceptions about the sociocultural NOS aspect. Before NOS training, Francine made a reference to the sociocultural NOS aspect by just listing culture as a factor leading to scientists' subjectivity. At the end of the professional development programme, she continued to connect the sociocultural 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. Unlike Francine, Andy could elaborate on how several social and cultural factors could contribute to the subjectivity in science at the beginning of the professional development programme. Andy thought that scientists' beliefs guide their study and these beliefs are influenced by social and cultural environment. At the end of the professional development programme, Andy continued to think that scientists' beliefs guide their work, but he started to emphasise 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 sociocultural background.

Only Francine expressed a clear misconception about the myth of the scientific method at the beginning of the professional development programme. She equated 'the so-called scientific method' with experimentation. During the pre-NOS interview, Francine mentioned how she taught 'the scientific method' by doing the classic paper towel absorbency experiment in her classroom. 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 at the beginning of the professional development programme. Francine thought that scientists use experimentation 99% of the time. At the end of the professional development programme, Francine realised her misuse of the term 'experiment'. She started to differentiate not every hands-on activity is an experiment and consider observation as important as experimentation in doing science. Unlike Francine, Nancy did not hold an obvious misconception about the myth of the scientific method at the beginning of the professional development programme. She expressed during the pre-NOS interview that not all scientists follow the same steps. However, she considered science as more procedural than art because she conceived of data collection as more procedural than creative. At the end of the professional development programme, Nancy no longer considered science as procedural because she started to acknowledge the role of creativity in collecting data as well.

Perceived effective features of NOS instruction

Specific focus on NOS content

All of the participants highlighted that they did not receive any instruction that specifically addresses what science is and how science works in their teacher education programmes and in the professional development programmes that they participated in previous years. Therefore, they found the specific focus on NOS content in this professional developmental programme very helpful for their understanding of NOS. For instance, Anna expressed the need for targeting different NOS aspects in order to develop a general understanding of science as follows: '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). Andy started the professional development programme with relatively informed NOS conceptions, but he did not know how to formulate his NOS conceptions using the appropriate NOS terms. He thought that being explicitly exposed to different NOS aspects during the professional development programme helped him to articulate his NOS conceptions by using a more appropriate language: 'I mean the more you study and learn about it [NOS] and practice and speak the language of it, the more you're going to be able to express yourself better' (post-NOS training interview).

Participation in hands-on NOS activities

Our participants credited certain NOS activities such as *Seven Blind Mice* children's book (Young, 1992) and the *Tricky Tracks* activity (Lederman & Abd-El-Khalick, 1998) for improving their NOS conceptions. For instance, after NOS training Nancy expressed that she started to consider science as a more creative and imaginative endeavour than before. During the interview, she explained the perceived changes in her creative NOS aspect by referring to a list of hands-on activities on NOS as seen in the following excerpt.

> The first author: What helped you to realize that science requires more creativity?
>
> Nancy: Well, I think some of the activities or the books [Jenkins & Page, 2003; Young, 1992] definitely were the ones; the *Bottle* activity was one because we really had to use our imaginations to think about what was inside that bottle that was causing that to happen. I just really never, I don't think, thought about it in those terms that scientists actually use their imaginations. I mean, I probably thought they did a little bit but not to the degree that I do now.

Andy also underscored the importance of participating in hands-on NOS activities by stating that NOS activities made abstract NOS ideas more concrete.

> So, I think that by doing that [discussing the history of science example on the tentative NOS], sometimes people feel that this is a very long and drawn out process whereas some of the activities we did – if it was the M*ice* [*Seven Blind Mice* children's book] or the B*ottle* or anything where you are trying to figure out what is going on, you all of a sudden see your idea 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 you down into something that was more tangible … I think it [a hands-on NOS activity] sort of provides a more concrete example to you that as opposed to something that's happened in history. (Post-NOS teaching interview)

Introductory readings about NOS

During NOS training, the participants read and discussed two articles on NOS: (1) McComas's (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, Weiland, Pongsanon, and Nargund's (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 NOS myths on their NOS conceptions.

After NOS training, Andy no longer used the terms 'prove' and 'disprove' to articulate his NOS conceptions. In his post-NOS training interview, he expressed that this change in his language might have resulted from reading McComas's (1998) article. Andy thought that reading the myths about NOS at the beginning of the professional development programme triggered his understanding that you cannot prove or disprove something in science. In other words, Andy perceived reading McComas's (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 realisation that experiments are not the principal route to scientific knowledge.

Similar to Andy and Francine, Anna also perceived the myth article as an effective feature of NOS instruction. She thought that the myth article coupled with other components of the professional development programme helped her to seek alternative NOS views that are more consistent with contemporary NOS conceptions.

> The researcher: 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 do not 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)

Even though Anna perceived reading introductory NOS readings as an effective feature of NOS instruction, she also pointed out the readings alone may not be sufficient for one to develop an appropriate NOS understanding. She thought an effective professional development programme on NOS should have a nice mixture of NOS readings, activities, and discussions.

Multiple types/forms of reflection

All of the participants perceived NOS training activities contributed to their learning of NOS when they were coupled with multiple types/forms 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 with the range of thoughts that arose from the learning experience, as seen in the below excerpt.

> 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. 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. (Anna, post-NOS training interview)

In addition to discussions with peers, all of the participants thought that their understandings of NOS were enhanced when they individually completed the structured worksheets that link the learning experience with NOS framework. For instance, Francine explained how the structured worksheets and discussions with colleagues contributed to her NOS learning 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. 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.
>
> 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 NOS understanding 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 source 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 for their students' NOS learning. They thought that such structured worksheets direct the learner's attention to important issues/questions and connect the experience to NOS content. Therefore, during their NOS teaching, the participants either used the worksheets that we provided or they developed their own worksheets to provide prompts to guide the reflective process.

Multiple exposures to NOS content

All of the participants thought that their understandings of NOS were enhanced because they had a chance to revisit the same NOS aspects across a variety of NOS activities and lessons. 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 as you are looking at the things on the poster [the NOS poster] and on the list [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. (Post-NOS training interview)

As seen in the above excerpt, Andy, and similarly other participants, considered the NOS poster or the list including the definitions of NOS aspects as a helpful tool to make references to 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.

Structural consistency

During NOS training, the participants followed the same structure: They first did NOS training activities such as readings on NOS or hands-on NOS activities and then they reflected on the learning experience by making references to NOS aspects presented on the NOS poster or in the NOS definition list. During their post-NOS training interviews or our informal talks after these interviews, they all highlighted that this structural consistency in NOS training significantly contributed to their NOS learning. After following the same structure many times, the participants came to realise that whatever they did in the activities would be connected to the poster or the list. In other words, the structural consistency helped the participants to connect their NOS learning experiences to the key points discussed during NOS training. For instance, Andy highlighted the structural consistency in NOS training as follows:

> 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 NOS training activities gave the participants an opportunity to assess elementary students' NOS conceptions. In this activity, teachers were provided with data from previously published studies about NOS and they were asked to assess students' NOS ideas as inadequate, adequate, or informed. Two of the four participants found this evaluation of secondary student data influential in their NOS learning. During their interviews, Francine and Nancy expressed that sorting a range of ideas on a particular NOS aspect based on their sophistication level forced them to clarify and reinforce their own NOS conceptions. For instance, Nancy realised that she needed to support her NOS ideas with examples because she learned during NOS assessment practice that the students' NOS ideas were considered as informed when they gave examples as a part of their answers.

The analysis of national and state science standards in terms of NOS

As part of our NOS training, we also asked the participants to examine and compare NOS content across three national science education policy documents (i.e. the Benchmarks for Science Literacy [AAAS, 1993], National Science Education Standards [NRC, 1996], and Next Generation Science Standards [NGSS Lead States, 2013]) and the science education standards in the state. This experience helped Andy and Anna to perceive NOS as an important part of elementary science standards. For instance, Anna 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' (NOS training field notes). Once Andy and Anna realised the coherence between the content of NOS training and their science standards, they were more likely to tune into NOS lessons that were covered during the training.

The implementation of NOS activities in the classroom

The professional development programme 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 NOS training activities in their classrooms. During their post-NOS teaching interviews, all of the participants perceived that the implementation of NOS activities in their classroom contributed to their NOS conceptions. For instance, Francine thought that her NOS conceptions about the tentative NOS aspect became fruitful after implementing 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. (Post-NOS teaching interview)

In addition to strengthening her NOS conceptions, Francine also acknowledged that 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)

Anna also talked about how her understanding of certain NOS aspects became clarified after implementing 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 after NOS teaching experience, it became obvious that both science and art need creativity and imagination, but science requires empirical evidence.

Discussion

The research question in this study investigated which components of the professional development programme were perceived as effective by elementary teachers in improving their NOS conceptions. Our findings revealed nine components contributing to the effectiveness of the professional development programme: (1) specific focus on NOS content, (2) participation in hands-on NOS activities, (3) introductory NOS readings (i.e. reading the article discussing the myths about NOS), (4) multiple types/forms of reflection, (5) multiple exposure to NOS content via a variety of activities, (6) structural consistency in the presentation of NOS content (first, reading or doing a hands-on activity on NOS and, then, reflecting on the learning experience from the perspective of NOS aspects with the help of visual aids), (7) the evaluation of secondary NOS data from elementary students, (8) the analysis of national and state science standards in terms of NOS content, and (9) NOS teaching experience.

The following paragraphs discuss the significance of our findings in terms of both teacher professional development and NOS perspectives. Our findings provide supporting evidence for Birman et al.'s (2000) three core features of an effective professional development programme. Birman et al. (2000) claimed that a professional development programme 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 programme effective because they perceived that they knew more about 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 NOS aspects after each NOS training activity, matching the content of the professional development programme with national and state science standards, and implementing several NOS activities in their own classroom encouraged coherence in their learning experiences.

Birman et al. (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 programme uses reform formats such as study groups and teacher networks in contrast to a traditional workshop or conference formats (reform vs. traditional format), (b) if the professional development programme ensures longer duration of professional development activities (shorter vs. longer in duration), and (c) if the professional development programme 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), our findings also underscored the importance of certain structural features in the effectiveness of the professional development programme. These structural features included the following: (a) multiple exposures to NOS aspects through an extended amount of time, (b) allocating specific time for discussing NOS aspects and NOS activities with peers as both a learner and a teacher, and (c) the opportunity to test what was learned during NOS training with their own students.

The identification of effective components of the professional development programme 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, 2007; Celik & Bayrakceken, 2012; Dass, 2005; Koenig 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. Our findings about the components of the explicit-reflective NOS instruction perceived as effective by elementary teachers in improving their NOS conceptions are both similar to, and different from, the findings of previous studies. For instance, making 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 NOS aspects through reflection in the context of activities or readings was effective in improving the NOS conceptions of elementary teachers (Abd-El-Khalick, 2001; Akerson et al., 2000, 2007; Celik & Bayrakceken, 2012; Dass, 2005; Koenig et al., 2012).

Different from previous NOS studies, our findings suggested the importance of different types/forms 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 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 that emerged from reflection is more powerful than reporting them orally.

In addition to the use of different types/forms of structured reflection, our findings revealed that the elementary teachers perceived the visual aids (i.e. the NOS poster and the definition list for NOS aspects), doing interviews with the researcher, and assessing elementary students' NOS ideas influential in their NOS learning because these professional development activities helped them to reflect on what they were learning in ways that allow them to deeply conceptualise and retain the target content. In this regard, our 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 for future practice

Our findings have several implications for teachers and researchers in the fields of science education and teacher education. Future NOS professional development programmes should take into account all nine features perceived effective by the elementary teachers in improving their NOS conceptions. There is a need for professional development programmes for elementary teachers that make NOS content the focus of their instruction. These professional development programmes should not only engage teachers in hands-on NOS activities, but also enable them to reflect on these learning experiences from an NOS perspective as an individual and then as a group of peers. These written or oral reflections followed by hands-on NOS activities should provide teachers an opportunity to retrieve their NOS conceptions, first, individually and then compare them with NOS conceptions of their peers. Such structural consistency in the delivery of explicit-reflective NOS instruction increases the probability of making connections between teachers' learning experience and NOS content.

In addition to hands-on NOS activities and multiple types/forms of reflection, future professional development programmes should also allocate specific time for teachers to introduce common NOS misconceptions and teaching techniques through introductory readings. In other words, future professional development programmes should balance the time allocated for hands-on activities, discussions, and readings on NOS. Such a balance would allow teachers to see NOS content across various contexts and solidify or elaborate on their NOS conceptions.

Future professional development programmes should also make NOS content relevant for elementary teachers by allowing them to assess their students' NOS conceptions, to evaluate national or state science standards in terms of NOS content, or to practise teaching NOS in their own classrooms. Such connections with their students or curricula allow teachers to not only clarify or enhance their NOS content and pedagogical content knowledge, but also understand the importance of teaching NOS in their classrooms. In agreement with Guskey (1985, 1986, 2002), 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, practising what was learned in a professional development programme 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.

Limitations of the study

The present study had several limitations. First, the findings of this study came from the participant teachers' attributions in response to the perceived changes in their NOS conceptions after participation in explicit-reflective NOS training. Thus, the study findings do not imply any causal relationships between the identified features and NOS conceptions. Future research could implement experimental designs to determine which of the identified features is actually effective or more effective in improving elementary teachers' NOS conceptions.

Second, the findings of this study are based on the learning experiences of four elementary science teachers who already started the professional development programme with adequate conceptions regarding certain NOS aspects and positive beliefs regarding teaching NOS and science. Given that prior knowledge or beliefs mediate one's learning (Pintrich, Marx, & Boyle, 1993; Posner, Strike, Hewson, & Gertzog, 1982; Strike & Posner, 1992), different groups of participants who start the professional development programme with more naïve NOS conceptions or negative beliefs about teaching NOS and science might show different types of changes, and thus, they might perceive different features to be influential in their NOS conceptions and teaching. Therefore, further research is needed to determine whether the study findings are applicable to other participant groups.

Third, the findings of this exploratory study are applicable to the four elementary teachers who worked at a high-achieving school giving high emphasis to science. Considering previous studies (Akerson, Cullen, et al., 2009; Akerson, Townsend, et al., 2009) had documented the influence of contextual variables (e.g. what is valued in the district or at the school) on NOS learning, the perceived effective features of explicit-reflective NOS instruction could vary at other schools which do not give much emphasis to science.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Appendix 1. The list of instructional materials used in NOS training

Instructional material	The use of instructional material in NOS training	Reason(s) for inclusion	Target NOS aspects
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.	The previous use of the article with teachers (Abd-El-Khalick & Akerson, 2004; Akerson et al., 2006; Morrison et al., 2009); To familiarise teachers with contemporary NOS views; To create *dissatisfaction* with existing ideas about science or generate *cognitive dissonance* to make participants explicitly aware of the inadequacies of their NOS views at the beginning of the intervention and help them to seek alternative views consistent with contemporary NOS views during the rest of the intervention (Abd-El-Khalick & Akerson, 2004; Akerson et al., 2000; McDonald, 2010; Schwartz & Lederman, 2002)	All nine NOS aspects
Bottle	During the activity, the instructor puts a string in a bottle the learners cannot see inside. Then the instructor flips over the bottle and stops holding it. Learners predict whether the bottle will fall down or stay in the air when released. Contrary to the learners' expectations, the bottle stays in the air with the string. Then the learners draw different models to explain the phenomenon (e.g. there is a magnet at the end of the string, which is attracted by the magnet inside the bottle).	To introduce the target NOS aspects; The previous use of *Black-box Activities* with elementary teachers (Abd-El-Khalick & Akerson, 2004; Akerson et al., 2006, 2007; Akerson, Cullen, et al., 2009; Donnelly & Argyle, 2011; Koenig et al., 2012; Matkins & Bell, 2007; Posnanski, 2010)	All nine NOS aspects
Seven blind mice (Young, 1992)	In this children book, six different-coloured 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	*Children Literature*, suggested by Akerson et al. (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, 2007); To reinforce NOS aspects	Empirical, inferential, tentative, creative, sociocultural, collaborative, and subjective NOS aspects
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	*Children Literature*, suggested by Akerson et al. (2010) to introduce or reinforce NOS aspects for young children; The previous use of children's	Empirical, inferential, tentative, creative, sociocultural, collaborative, and subjective NOS aspects.

(*Continued*)

Continued.

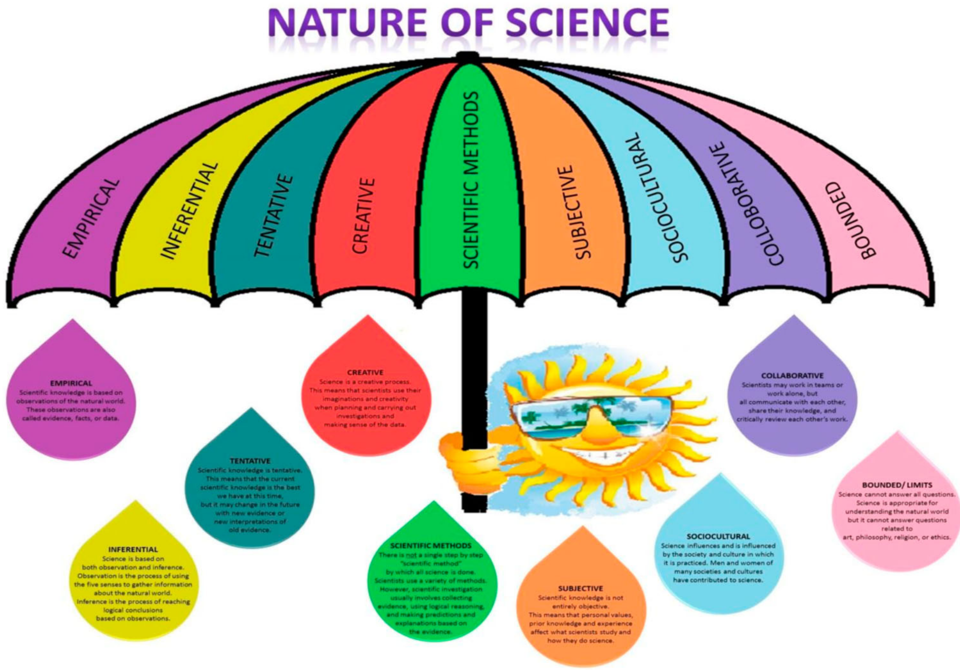
Instructional material	The use of instructional material in NOS training	Reason(s) for inclusion	Target NOS aspects
	which animal each part belongs to and how it is used.	literature books with elementary teachers (e.g. Akerson et al., 2000, 2007); To reinforce NOS aspects	
Fossils (Lederman & Abd-El-Khalick, 1998)	During this activity, teachers play the role of a palaeontologist. 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, behaviour, and other characteristics of the organism.	*Contextualised NOS activity* because of the presence of the topic 'fossils' in the elementary science curriculum; The previous use of the activity with elementary teachers (Koenig et al., 2012; Matkins & Bell, 2007); To reinforce NOS aspects	Empirical, inferential, tentative, creative, sociocultural, collaborative, and subjective NOS aspects.
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.	*Decontextualised NOS activity* The previous use of the activity with elementary teachers (e.g. Akerson et al., 2000, 2006, 2007; Donnelly & Argyle, 2011; Posnanski, 2010); To reinforce NOS aspects	Empirical, inferential, tentative, creative, sociocultural, collaborative, and subjective NOS aspects
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.	*Decontextualised NOS activity* To reinforce NOS aspects	Empirical, inferential, tentative, creative, collaborative, subjective NOS aspects, and the absence of the scientific method
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.	*Decontextualised NOS activity* The previous use of black-box activities with elementary teachers (Abd-El-Khalick & Akerson, 2004; Akerson et al., 2006, 2007; Akerson, Cullen, et al., 2009; Donnelly & Argyle, 2011; Koenig et al., 2012; Matkins & Bell, 2007; Posnanski, 2010); To reinforce NOS aspects	Empirical, inferential, tentative, creative, sociocultural, collaborative, and subjective NOS aspects
Article on NOS teaching strategies (Akerson et al., 2010)	Teachers read and discuss Akerson et al.'s (2010) article on a research-based model and strategies for teaching NOS to young children.	To introduce NOS teaching strategies; To discuss developmental appropriateness and the importance of teaching NOS aspects	NA
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	Previous use of the examination of local and state benchmarks for NOS references with teachers to develop NOS pedagogical content knowledge (Posnanski, 2010);	All nine NOS aspects

(*Continued*)

Continued.

Instructional material	The use of instructional material in NOS training	Reason(s) for inclusion	Target NOS aspects
	[NRC, 1996], and NGSS [NGSS Lead States, 2013]) and State Science Standards for K–5 education.	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	
NOS poster	After each NOS activity, the instructors refer to the NOS poster that includes the definitions of the target NOS aspects (See Appendix 2 The NOS Poster developed by the researcher).	The use of visual aids was suggested by Akerson et al. (2010) to introduce or reinforce NOS aspects for young children.	All nine NOS aspects
Assessment of elementary students' NOS ideas	Teachers first individually and then collaboratively categorise given students' ideas into an inadequate, adequate, or informed NOS idea for the empirical, inferential, creative, tentative, and subjective NOS.	Inspired from NOS card-exchange activity (Cobern & Loving, 1998) to reinforce the acquired NOS views; The analysis of NOS views of students was found to be effective for improving NOS views of the instructors of preservice elementary teachers (Hanuscin, Akerson, & Phillipson-Mower, 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 & Akerson, 2004, 2009)	Empirical, inferential, creative, tentative, and subjective NOS aspects

Appendix 2. The NOS poster



Note: The poster was developed by the researcher (Adibelli, 2015) using the definitions of NOS aspects on Sweeney's (2010) questionnaire of Ideas about Science for Early Elementary (K–4) Students.

Appendix 3. 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.

YOUR OBSERVATION What do you see on each side of the cube?	PATTERNS What patterns did you figure out on the cube?	YOUR INFERENCE What is on the bottom of the cube?

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?
5. How do you think what you have done is similar to the work of scientists? Check each nature of science idea that you recognised during this activity. Write a few keywords 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:

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, 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.