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SI: NATURE OF SCIENCE

Improving Science Teachers' Views about Scientific Inquiry

Reflections from a Professional Development Program Aiming to Advance Science Centre-School Curricula Integration

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Abstract
The present study specifically focuses on science teachers' views about scientific inquiry and their use of scientific inquiry in their lesson plans, which were prepared at a professional development workshop designed for better utilization of science centers (SCs). As an impact evaluation research, qualitative data was collected from 41 purposively selected volunteer science teachers. The project team provided the participants with intense instruction in inquiry, and fostered them to learn nature of science and nature of scientific inquiry explicitly. The participants designed lesson plans that integrate school science curricula with exhibits at SCs before and after the workshop. An open-ended questionnaire about the views about scientific inquiry (VASI) was administered before and after the workshop, and teachers' post-lesson plans were analyzed to detect the presence of scientific inquiry aspects. The majority of teachers exhibited improved views about scientific inquiry based on the VASI instrument. Also, lesson plan analyses indicated that teachers, who showed more improvement in VASI, included more scientific inquiry (SI) elements in their post-lesson plans. It was observed that science teachers' lesson plans are limited in terms of teaching science in line with real scientific inquiries in SCs to make students learn about the nature of scientific inquiry while learning science. Only two groups embedded SI properly in the SC-oriented lesson plans, and teachers rather used inquiry-based methods of teaching (e.g., argumentation, predict-observe-explain) and process skills (e.g., questioning, explanations). Accordingly, further studies are suggested to develop a specific pedagogical content knowledge framework for teaching with/in SCs.

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1 Introduction

The frameworks constructed to train teachers about informal science learning environments are progressing (Astor-Jack et al. 2007; Monteiro et al. 2016) remarkably due to their prominence in science education research and policy. These settings are perceived to supplement and extend school science learning, promote scientific literacy, and increase public engagement with science (Gutwill and Allen 2010, 2012; Feinstein and Meshoulam 2014; Luehmann and Markowitz 2007). Collaborations between schools and science centers have the potential to expand the proposed benefits of these settings provided that teachers are competent in teaching and guiding students in these places. Thus, professional development is perceived to be the key in order for teachers to acquire the skills and knowledge necessary to pursue and develop students' science interests and to make them engage in scientific inquiry in informal settings (National Research Council, NRC 2009, p. 15). Although some informal learning environments (e.g., Exploratorium, San Francisco Museum, Boston Science Museum) offer teacher professional development programs, according to Astor-Jack et al. (2007), the main purpose of such programs is to advance students' learning through inquiry-based science teaching practices. Therefore, comprehensive professional development programs are required to train teachers about students' learning in out-of-school environments.

Luehmann and Markowitz (2007) presented empirical evidence to support the idea that out-of-school environments have opportunities to engage students in scientific inquiry (SI). Similarly, Gutwill and Allen (2012) stated that science centers (SCs) are perfect places to provide SI activities. During a SC visit, students play with exhibits, try experiments, and make observations and inferences. In such experiences, their inquiry skills are improved if teachers or explainers guide them appropriately. Additionally, a SC provides a learning environment for teachers in which direct investigation of natural phenomena is offered by many scientific inquiry resources usually not available in schools. In such learning environments, students have the opportunity to understand both nature of science (NOS) and nature of scientific inquiry (NOSI). In an effective SC visit, students have the possibility to learn how scientific inquiry is conducted along with evaluating the validity of scientific claims as well as how scientific knowledge is produced. According to Schwartz et al. (2012), individuals are required to comprehend nature of scientific inquiry, NOSI, since this is critical in developing and accepting scientific knowledge. Research on the understanding of NOS states that learners and science teachers do not usually hold sufficient informed understanding of NOS (Driver et al. 1996). Yet, there are some other works revealing that, in terms of certain NOS aspects, teachers may hold strong conceptions (Vázquez-Alonso et al. 2013). When it comes to SI, Lederman et al. (2014) made a similar claim, mainly that "neither teachers nor students typically hold informed views of SI" (p. 66). Crawford (2014) defined learning about scientific inquiry as including both doing inquiry (its practices) and learning about nature of scientific inquiry. According to Gutwill and Allen (2012), informal science learning environments may bridge formal and informal science education by improving scientific inquiry practices to meet such needs at schools. When teachers are trained to have exploration, discovery, and science process skills rather than transmitting factual knowledge in SCs, they may plan better visits to promote their own and their students' understanding about scientific inquiry.

Studies focusing on teachers' development about informal settings point out that they are usually not aware of how to benefit from science centers (Cox-Petersen et al. 2003). Yu and Yang (2010) stated that teachers rarely teach at science centers and that they rather prefer explainers to guide students. In that perspective, we believe that science centers deserve more research attention to assess their potential to contribute to both teachers' and students' understanding of scientific inquiry practices. Such claims justify the need for developing, implementing, and sustaining more professional development models for integrating informal and formal settings to benefit from science centers, especially regarding scientific inquiry practices. According to Monteiro et al. (2016), teachers need to know the resources exhibited in SCs before a visit. Similarly, NRC (2009, 2011) argued for the necessity of teachers' participation in professional development programs that include pedagogic strategies specific to informal settings, and to be introduced to the scientific content presented at these learning environments in order to effectively implement educational reforms.

Based on these claims, in this study, a professional development workshop enriched with specific activities is described and its impact on the teachers' views about scientific inquiry and their lesson plans is discussed. Specifically, the study investigated the role of a professional development workshop on the teachers' views about scientific inquiry and their use of inquiry elements in their lesson plans since these facilities are expected to contribute to their repertoire of teaching in informal environments.

2 Theoretical Background

2.1 Understanding of and about Scientific Inquiry

Before describing the understanding of and about scientific inquiry, we may need to highlight some debates on the concept of NOS. Klopher (as cited in Erduran and Dagher 2014) described nature of science as "the processes of scientific inquiry and the developmental nature of knowledge acquisition in science" (p. 4). According to the review of Chang et al. (2010), the literature of NOS between 1990 and 2007 contains some key outlined sets of statements referred to as the "consensus view" of nature of science aspects; these are tentativeness, observation-inference, theory-laden, creativity and imagination, social and cultural embeddedness, theories and laws, and methods of science. Relying on this "consensus view," a large body of empirical studies has been conducted (e.g., Abd-El-Khalick and Lederman 2000; Akerson and Donnelly 2008). Although many researchers in the science education community agree with these key aspects of NOS, several debates have emerged for a concise description of what constitutes NOS (e.g., Allchin 2011; Driver et al. 1996; Erduran and Dagher 2014; Garcia-Carmona and Acevedo-Diaz 2018; Irzik and Nola 2011; Kampourakis 2016; Lederman 2007; McComas 1998; Matthews 2012). Some authors (e.g., Lederman 2007) have suggested that while NOS and scientific inquiry are related, they should be differentiated. The premise for this claim is that "inquiry" has been "as the methods and procedure of science while the NOS concerns more the epistemological features of scientific processes and knowledge" (Erduran and Dagher 2014, p. 6). According to Irzik and Nola (2011), excluding scientific inquiry from NOS is artificial, since scientific inquiry such as data collecting, classifying, analyzing, experimenting, and making inferences are all parts of science, and this fact itself should be included in NOS. The debates are indication of how differently the nature of scientific inquiry is conceptualized among science educators.

Schwartz et al. (2004) described "scientific inquiry (SI)" as the methods and activities that lead to the development of scientific knowledge. According to Lederman et al. (2014), SI is the processes of "how scientists do their work and how the resulting scientific knowledge is generated and accepted" (p. 66). Lederman (2009) stated that SI is the combination of general science process skills with traditional science content, creativity, and critical thinking to develop scientific knowledge. Students are expected to have both abilities necessary to do inquiry (NRC 2011) and a fundamental understanding about particular characteristics of SI (NRC 2000). Moreover, Lederman et al. (2014) stated that SI and NOS are used interchangeably, adding that despite their dependence, the difference is that NOS encapsulates the differentiation of science from other fields as to how knowledge is developed, whereas SI is the process or way scientists do science, produce, and justify scientific knowledge (Schwartz et al. 2008; Schwartz et al. 2012; Lederman et al. 2014). According to Schwartz et al. (2008), NOS and NOSI or such science processes are often conflated or combined under a more general "students' understandings of science." The notions about the methods of science are often placed under the umbrella of "NOS." They state that although the distinction between NOS and NOSI is incomplete, with areas of overlap and connectivity, "NOS aspects are those that pertain most to the product of inquiry, the scientific knowledge. NOSI aspects are those that pertain most to the processes of inquiry, the "how" the knowledge is generated and accepted" (p. 3).

Epistemological views of science involve one's view of scientific knowledge as a way of knowing and explaining the natural world, i.e., NOS. On the other hand, one's view of the nature and rationale of the processes through which that knowledge is constructed and justified is considered as NOSI by Schwartz et al. (2008). Related to the processes of inquiry, there are some other views, too. For example, Erduran and Dagher (2014) referred to "how scientific research is done" as "scientific practices." They mentioned that "processes," "activities," and "practices" are used synonymously to refer to aspects of science, and these terms' precise attributes are guided by their theoretical assumptions. Garcia-Carmona and Acevedo-Diaz (2018) used the term "scientific practice" and stated that it would "integrate aspects related to the way of knowing and the set of processes followed by scientists in their research. Consequently, meta-knowledge about the issue would constitute what is known as the nature of scientific practice, which itself constitutes a subset of NOS" (p. 439). Based on these descriptions of NOS and NOSI, in this study, NOSI is considered as a subset of NOS since scientific knowledge is constructed and justified through SI.

To grasp science as an inquiry, one should nurture the skills needed to do inquiry and comprehend SI in terms of how scientists work and how knowledge is confirmed by scientific community (Schwartz et al. 2008). Schwartz et al. (2008, p. 4) provided a framework for the description of NOSI, namely, that (a) scientific investigations are guided by questions, (b) scientists use multiple methods, (c) there are multiple purposes behind scientific investigations, (d) scientific knowledge is justified with evidence and data, (e) recognition and handling of anomalous data is a critical part of progress in science, (f) there is difference between data and evidence, and (g) there is a community of practice impacting scientific inquiry. Schwartz et al. (2008) developed the views of scientific inquiry (VOSI) instrument to assess NOSI aspects. Then, Lederman et al. (2014) constructed a new tool, views about scientific inquiry (VASI), which focuses on some similar and additional NOSI aspects. VASI was designed and validated to measure individuals' views of NOSI aspects thorough eight aspects of NOSI. These aspects are: "scientific investigations begin with question and do not necessarily test a hypothesis," "there is no single method of doing science," "inquiry procedures are guided by the question asked," "scientists performing the same procedures may not get the same results," "inquiry procedures can influence results," "research conclusions must align with the data collected," "data is not the same as evidence," and "explanations are developed from a combination of collected data and what is already known."

Research demonstrates that, similar to studies focusing on understandings of NOS, neither teachers nor students necessarily hold informed views of SI (Driver et al. 1996; Schwartz et al.

2002). Studies concerning SI are relatively less than those of NOS, possibly due to the lack of an assessment tool. After the construction of VOSI and VASI, few studies attempted to explore NOSI views. Leblebicioglu et al. (2017) investigated middle school students' changes of views about NOSI aspects during a science camp. Senler (2015) compared Turkish middle school students' views of NOSI with those of students from the USA. According to Gutwill and Allen (2010), visitors at science centers engage in inquiries at exhibits for no longer than a few minutes. Then, one can conclude that visitors lack the skills for inquiry or that teachers/explainers do not possess the essential skills needed to allow visitors to deeply investigate the phenomena at such exhibits. Burgin and Sadler (2016) mentioned that out-of-school experiences might provide a learning environment where individuals are engaged in authentic activities or practices that have the potential to influence the understandings related to nature of science. This research-based evidence justifies the need for professional development programs to support teachers in doing scientific inquiry in informal settings, where participants can ask questions, think critically, perform inquiries and discuss ideas about NOS and science concepts.

2.2 Informal Science Environments, Teacher Professional Development about Scientific Inquiry

According to Bybee (2000), the meaning of "inquiry" in science education varies and it can also be used as a method of scientific inquiry. Bybee stated that "science as inquiry" contains three elements, these are as follows: skills of scientific inquiry, knowledge about scientific inquiry, and pedagogical approaches for teaching science. The aspects are the following: asking questions, making observations, predicting phenomena, performing experiments, making explanations, and communication with others about ideas are accepted as scientific inquiry skills and are widely perceived to be fundamental to science learning in formal/informal settings (e.g., Gutwill and Allen 2010, 2012; Leblebicioglu et al. 2017; Luehmann and Markowitz 2007; NRC 2009). According to NRC (1996), an effective science teacher needs to possess the theoretical and practical knowledge and abilities concerning science, learning, and science teaching. However, based on Mundry and Loucks-Horsley (1999), teachers usually do not have the adequate content knowledge required to transform reform-based ideas into practice, and they are not able to choose, design, and perform appropriate teaching practices.

With the help of professional development programs, science teachers may be familiarized with SCs as places to provide different exhibits, shows, and workshop halls in which visitors' inquiry skills can be elicited and scientific investigations can be promoted. Through professional development programs about informal science learning environments, teachers can utilize such environments in order to promote students' knowledge, competencies, skills, and attitudes by using inquiry-based teaching methods. Fruitful activity structures have the potential to produce good and useful learning environments in which teachers can experience reform-based practices that require more emphasis on student thinking and learning (e.g., inquiry) rather than rigid methods of instruction (e.g., lecturing). To support this, Adams and Gupta (2017) stated the importance of informal science learning institutions as places that serve as partners to university-level teacher education programs. They described how such institutions can offer unique learning opportunities for teachers' professional development. Provided that teachers are trained, there is empirical evidence to support the argument that out-of-school settings can provide opportunities for engaging students in SI and investigations with authentic scientific data (Luehmann and Markowitz 2007).

NRC (1996) stated that the professional development (PD) of science teachers should be accomplished by actively involving teachers in scientific investigations that would allow them to examine both the content and process of science and incorporate opportunities for reflection and collaboration. In addition, good science teacher training comprises content knowledge (Avraamidou and Zembal-Saul 2010), pedagogy knowledge (Astor-Jack et al. 2007; NRC 2000), pedagogical content knowledge (Loucks-Horsley et al. 2010; Loughran et al. 2003), knowledge and beliefs about context, integration of inquiry-based activities into the classroom practices (NRC 1996), and finally how to organize a successful field trip (Smith et al. 1998). There have been a number of studies reporting on pre-service teachers' professional development in SI related to out-of-school science environments (e.g., Kelly 2000; Avraamidou 2015), few related to university-museums collaborations and out-of-school programs for teacher preparation (e.g., Kisiel 2013; Luehmann and Markowitz 2007) and collaborations between SC and higher education institutes regarding inquiry-based activities (Luehmann and Markowitz 2007); however, there is no empirical work measuring in-service teachers SI through a SC related PD programs. Luehmann and Markowitz (2007) described out-of-school environments as places that provide chances to engage students in SI. Preparing a PD program proposing to improve teachers about understanding SI may be expected to assist them and their students to deal with authentic scientific data in these places. Lederman et al. (2014) stated that "the persistent belief equating the doing of inquiry with understandings about inquiry, as well as the common conflation of NOS with SI, are both partially to blame" (p. 66). Besides, Lederman (2019) contextualized both nature of scientific knowledge and SI over the same activity, and suggested an explicit instruction for teaching these concepts. Therefore, further investigation may be necessary to look at whether explicit NOS and NOSI instruction in a PD program for SCs with appropriate activities that supports teachers to hold correct understanding of SI.

Some studies encapsulate pedagogical content knowledge as a theoretical framework concerning teachers' development (see Abell 2007; Loughran et al. 2003). In the present study, teachers' professional development relies on the (1) Shulman's (1986) pedagogical content knowledge (PCK), and (2) the constructivist theory of science teaching. In that sense, the context of the PD program establishes the ground on which teachers' PCK is carried out through inquiry-based scientific practices. The context of this study that teachers are assumed to be developed about is the facilities of SCs as a learning environment. Additionally, their development concerning nature of scientific inquiry views is operationalized through VASI items, and teachers' use of NOSI aspects and their use of methods of scientific inquiry in their lesson plans. Moreover, based on constructivist theory, inquiry can be characterized as both an orientation, such as NOS, and a process such as method of science (Eick and Reed 2002; Bianchini and Colburn 2000). Assuming that teachers' views of NOSI will be concurrent with their use of inquiry-based practices in SCs and their use of inquiry as a method of constructivist science teaching, this study specifically investigates how a comprehensive science teachers' professional development program related to science centers affects their understanding of NOSI, their use of NOSI and methods of scientific inquiry in the lesson plans.

2.3 Significance and Objective of the Study

The professional development of science teachers about informal learning environments is essential since these places are perceived to extend beyond classrooms in order to develop a better understanding about NOS and NOSI aspects that are necessary for teaching and learning in science centers. Science teachers can learn science content through scientific inquiry practices, as well as understand the nature of science and the nature of scientific inquiry in science centers. After that, they may transmit their knowledge to their students. Despite the research on the impacts of professional development programs within informal learning (Gutwill and Allen 2012; Loucks-Horsley et al. 2010), few studies have explicitly explored the effects of those programs on teachers' views about scientific inquiry by using the VASI instrument and also science teachers' lesson plans. Thus, in this article it seems reasonable to conduct a systematic research on the effectiveness of the proposed professional development program about science centers related to the participating teachers' views about nature of scientific investigation. Specifically, the research questions are as follows:

- How does a professional development program, enriched with inquiry activities, affect science teachers' understanding of nature of scientific inquiry?
- How does a professional development program impact science teachers' use of nature of scientific inquiry aspects in their lesson plans developed to integrate science centers with school curricula?

3 Method

This study uses a qualitative approach to immerse fully in data regarding teachers' professional development related to VASI and their lesson plans regarding a visit to a SC. The study evaluates the impact of a professional development program, hence being an applied research. According to Neuman (2014), applied research is usually employed by educational institutions and governments in order to address a specific concern, which in the present article is teachers' development related to their views about scientific inquiry. Evaluation research, as a type of applied research, assesses the changes that can be attributed to a particular intervention. How a teachers' professional development program affects their views about SI and their lesson plans are also evaluated.

3.1 Sample

Forty-one volunteer science teachers (26 females and 15 males) participated in a full-length workshop. Their years of experience ranged between 2 and 25. All teachers were teaching science courses at elementary state schools for grade levels from five to eight which constitutes for ages from 11 to 14 and all had at least a bachelor degree from university science education departments. Three teachers had masters' degrees, one was a PhD student, and four were masters' students. The youngest teacher was 25 years old and the oldest was 49. The mean age of the teachers was 34.7. Although 568 teachers applied to participate in the workshop, due to time and place limitations, only 41 were selected. The selection criteria included whether the teacher had participated in a professional development program before and whether they were working in a city with a SC or a city close to another one having a SC. All teachers' participation in this workshop was approved by the Ministry of Education, and an Ethical committee approval was received from the same Ministry as stakeholder of the project. Seven groups of 6 teachers were formed based on the number of male and female participants and years of experience. Throughout the workshop, each teacher worked with his/her group members.

3.2 The Project

This work is part of a 3-year research project supported by The Scientific and Technological Research Council of Turkey, aiming to facilitate teachers' teaching and learning activities in

SCs. More precisely, the project's PD model consists of 9 different modules (Table 1) proposing to train teachers in terms of teaching and learning science in and with SCs.

The first module is designed for increasing awareness and knowledge about the role of SCs in science communication. The second one describes SC in detail through a visit and examination of exhibits and other tools for learning at these centers. The third is about collaborative hands-on activities with varying strategies of teaching to advance learning. The fourth module includes specific activities to improve teachers' views and knowledge about NOS, and how to embed this knowledge into SCs. The fifth module proposes to facilitate discourse in these centers. The sixth one is planned to make teachers aware of how to use science shows in their lessons and how to incorporate such events into curricula. The seventh module focuses on developing desktop applications of some exhibits at SCs for in-class utilization. Following these, the eight is about specific implementations of teaching and learning for SC. Finally, the last one is about designing lesson plans for school SC integration, (see Table 1 for sessions in each module and sample activities).

NOS and science teaching with inquiry was the main ground to create discussions in order to expand teachers' knowledge and beliefs about teaching and learning in SCs. NOS emphasis was explicitly included in almost all of the modules of the PD program. In addition, in almost all training modules, the work was done collaboratively and teachers participated in hands-on and minds-on inquiry activities. When examining the literature on PD for informal environments of science teachers, we noticed some implementations concerning the use of pedagogical approaches. In this project, the majority of the modules as well as the activities are specific to this project through which 10 different workshops were conducted; some were performed at SCs in different cities, and others at a university. In the workshops organized at the SCs, teachers and SC explainers worked together and learned about their views and expectations. During the project, a few volunteer teachers were observed in their classrooms while teaching certain topics by using SC facilities. Moreover, two different teachers were observed during a SC visit with their students. Four teachers were mentored after the workshop; these teachers prepared projects with their students at informal learning environments. One teacher investigated the difference between her students' interests and achievements; she compared the responses of those who learned the topic before the SC visit and those who did so after the visit. Overall, 18 different investigations conducted in collaboration with teachers. It is worth mentioning that, even though the project is now complete, some teachers are still receiving mentorship from the project team.

3.3 Study Context: The Workshop

The workshop in this study was conducted at a state university in Ankara, Turkey where two different science centers, natural history museums, and other informal science settings exist. Researchers discussed with teachers how to organize effective SC visits since they have expressed concerns about their own lack of knowledge of SCs. Then, they were taken to a SC to explore the opportunities and facilities. During the visit, the project team asked teachers to work in groups and generate questions that could be answered through an investigation in the SC using its facilities, and then prepare a lesson plan about an effective SC visit. Some of the participating teachers in this study had never visited a SC before the workshop. After gathering information as to their general view about SCs, participants actively engaged in the hands-on and minds-on collaborative activities enriched with scientific inquiry practices that would require them to work together and think about how to integrate the school science

Table 1 The modules of professional development program and sample activities

Module 1	Module 2	Module 3	Module 4	Module 5	Module 6	Module 7	Module 8	Module 9
1 sessions Science society com	2 sessions SC, learning in and with SC	4 sessions Learning theories and teaching strategies at SC	4 sessions What is Science? nature of science and teaching science	2 sessions Discourse analysis in SC and com skills	2 sessions Developing experimental systems modeling exhibits at SC and science demos	2 sessions Implementing science lessons that models exhibits at SC	2 sessions Ateliers in SC & teaching in them	1 sessions Developing lesson plans integrating SC and its implementation
Sample activities								
Discussion: role of science society com	SC visit, lesson plans, world café: an effective SC visit	Argument driven--inquiry: let us make a cold pack	Measurement of the Earth's Circumference, New Society	Indicator show, flame colors of salts of transition metals	Magic flasks, liquid nitrogen show	DNA analysis & genetically modified organisms (GMO) detection	Let's design a robot, STEM activities	Designing a detailed lesson plan to integrate SC

Com, communication; *SC*, science center; *Demos*, demonstrations curricula with the facilities available at the SCs. Teachers worked in groups of 6 throughout the workshop, which was composed of nine modules including 20 sessions, each one lasting 1.5–2 h. The workshop lasted 1 week in the month of July, 2017 while the teachers were on summer holiday. Module 4 was entirely dedicated to explicit and reflective NOS and NOSI teaching. In other modules, there were many inquiry-based activities embedded in the sessions (see Table 1). All workshop sessions were guided by science education faculty members. At the end of the project, the proposed modules were transformed based on the needs assessment studies conducted at the initial stages of the project and the gained experiences throughout the progression of the project. The modules concerning Inquiry, SI, and NOS remained the same in all workshops, as these concepts are perceived to be essential for informal learning, and based on observations, teachers significantly benefited from these modules.

Relying on the fact that NOS and NOSI are intersected, and knowing that for producing scientific knowledge, it is necessary to understand the way scientific knowledge is produced, we find it extremely necessary to improve the teachers' understanding of NOSI and NOS at the same time. Educational research supports the idea that explicit-reflective NOS teaching advances improved views of these concepts. Thus, specific activities (Table 2) were prepared for explicit-reflective NOS and NOSI teaching, some others were adapted from the literature, and the rest were specifically developed for this project. Additionally, throughout the workshops, in inquiry-based activities teachers were encouraged to develop NOS conceptions aligned with accepted contemporary views and appropriate aspects that could be inferred from both the context and the content of the module. According to Schwartz et al. (2004), implicit messages within acts of inquiry refer to the absence of specific attention to NOS. As Schwartz et al. (2004) stated, within any science instruction, implicit messages about NOS are communicated but these approaches are ineffective in attaining NOS. The main assumption was that engaging teachers in explicit inquiry-based pedagogical approaches would provide inquiry-based learning opportunities with the added instructional component of specific attention to NOS and NOSI aspects.

In the first session, the teachers were evaluated about their knowledge about SCs as well as their awareness of the facilities of SCs. In the second session, the project was introduced, followed by the third session, in which they visited a SC. The 2nd, 3rd, 4th, 5th, 6th, and 7th sessions were especially about learning at these centers and appropriate teaching strategies were employed based mainly on inquiry, such as guided inquiry, predict-observe-explain (POE) strategy, argumentation, and argument-driven inquiry. The sessions were enriched with activities that teachers actively participated in by doing inquiries. An activity was conducted on the 5th session entitled "Let's Make a Cold Pack," in which NOS and NOSI aspects were discussed explicitly through argument-driven inquiry. All these activities supported learning environments in which the role of inquiry process in science, argument-based discussions, technology and modeling in science were discussed through discourses between teachers and researchers. There were many well-known activities for explicit reflective NOS teaching in Module 4, mainly in sessions 8, 9, 10, and 11. NOS activities were used paving the way for NOSI aspects to be handled within appropriate content and context.

The 12th, 13th, 14th, and 15th sessions were about developing activities that model exhibits at SCs, their in-classroom applications, and science demonstrations. The activity "Magic Flasks" was specific to this PD program and it was inspired by the work of Banu Musa Brothers. In a well-known SC in the study context, there is an exhibition system which is called "Sultans of Science." In this exhibit hall, based on the works of Muslim scholars, some machines and devices are exhibited. The Banu Musa brothers, Muhammad, Ahmad, and al-

Table 2 Some activities supporting NOS and NOSI discussions in science centers

The activity	Included NOS aspect	Link with SC exhibit	Understanding of NOSI aspects expected
Black Box (Lederman and Abd-El-Khalick 1998)	Observation, empirically bases, tentativeness, creativity and imagination, subjectivity,	Sultans of Science	Starting with a question, no single set and sequence of steps followed in scientific investigations, inquiry procedures can influence the conclusions, and conclusions must be consistent with collected data. Explanations are developed from a combination of collected data and what is already known.
Measurement of the Earth's Circumference	Observation, empirically bases, tentativeness, creativity and imagination, Observations and inferences subjectivity	Astronomy related exhibits	Scientific investigations all begin with a question but do not necessarily test a hypothesis, no single set of steps followed in scientific investigation, difference between data and evidence, inquiry procedures influences the conclusion, Explanations are developed from a combination of collected data and what is already known. Inquiry procedures are guided by question asked.
New Society (Cavallo 2008)	Observation, empirically bases, Socially and culturally embedded, creativity, imagination, theory-laden, subjectivity no single method	Almost all exhibits	Scientific investigations all begin with a question but do not necessarily test a hypothesis, no single set of steps followed in scientific investigation, same procedures may not get the same result, inquiry procedures can influence the conclusions, research conclusions must be consistent with the data collected, Explanations are developed from a combination of collected data and what is already known

Hasan, were three of the most prominent and creative scientists of the golden age of Muslim civilization, they lived in the ninth-century Baghdad and worked in the fields of mathematics, astronomy, and mechanics. They are well-known by their achievements in mechanics and their most famous book in that area, “The Book of Ingenious Devices” describes a total of 100 devices with large illustrations and how to use them. In this exhibit hall, there was a system inspired by an apparatus originally designed by Banu Musa Brothers, which is a system with hidden inner workings. Designing a “Magic Flask” activity is also similar to the “Black Box” activity, where there is an enclosed box with two funnels on top. The activity creates a learning environment for students and science teachers in which they can relate the history and nature of science, as well as the nature of scientific inquiry, to informal learning environments through explicit-reflective instruction. They experienced the notion that, in some cases, only limited data can be directly observed and that an inferred explanation or model can be constructed in such cases. In other words, such activities are used to infer that most phenomena that scientists investigate cannot be “directly” observed (e.g., atoms, black holes, and reaction dynamics). Teachers did their own investigations and made their own models to design the “Magic Flasks” system. Their investigations modeled how scientists do science and how scientific knowledge is produced. Their models were similar to the exhibit called “Sultans of Science” in that particular SC. In these kinds of activities, the participants started with a question, carried out the investigations and discussed NOS and NOSI at the end of the activity. The aspects covered in some activities are provided in Table 2. Another inquiry-based activity was “Measurement of the Earth’s Circumference” with examples from the history of science, in which many NOS and NOSI aspects are also addressed explicitly.

In line with the literature, the project team used both content-generic and subject-specific activities for promoting NOS and NOSI understanding. For example, “The New Society” (Cavallo 2008) activity was a content-generic activity. The teachers were introduced to the aspects of NOS; tentativeness, how scientific knowledge is based on observation and experiments, inferences, how it can be theory-laden and subjective, social and cultural factors, the role of creativity and imagination, no universal step for science, and finally, the place of serenity in science over this activity. Similarly, the “Black Box” activity (also known as “the water machine” activity in Lederman and Abd-El-Khalick 1998) was also content-generic and embodied a majority of NOS and NOSI aspects. In order to explore the design of the “Black Box,” teachers started with questions, made observations, derived inferences accordingly, used their creativity, and also applied their own methods to design a model.

There were also content-embedded activities to support NOS and NOSI together. For example, in the “Measurement of the Earth’s Circumference” activity teachers discussed the history of science, explored what is science and how scientific investigations are carried out. This activity was designed in the context of the history of science, and teachers discussed how Eratosthenes, who lived in the 200s B.C., calculated the circumference of the Earth. This was an inquiry-based activity guided by the researchers. The discussion started from different views related to the shape of the Earth, the first stating that the Earth is flat and the second stating that it is spherical. Some NOS tenets such as tentativeness, observation-inferences, and social-cultural embeddedness were also addressed explicitly. The teachers expressed their ideas about the issue with their claims and evidence. The role of asking questions and doing inquiry based on the question was discussed. Participants were asked about the method that Eratosthenes used in his investigation. The role of observation as a method of scientific investigation was also a topic, and the teachers worked in groups and were asked to calculate the Earth’s circumference. The group members discussed and planned their investigations using their prior knowledge and what was already known about their inquiry. The activity was carried out in daytime and teachers were able to measure the angle formed by a meterstick's shadow. Using the required materials and additional information provided for them, in this way, they explicitly engaged in a scientific inquiry process guided by the researchers. They had a number of questions, based on which they followed some steps to collect data, such as measuring a shadow. From the collected data, they calculated new variables, such as the angle. The distance between the city and the equator was also part of these data, using which the teachers made some inferences with their mathematical knowledge. The angle of shadow in the city divided by 360° would be equal to the distance between the two cities. Teachers explained their reasons for making this calculation. Some groups could not collect enough data to provide sufficient evidence for a conclusion. At the end of the activity, the groups summarized their questions, methods of inquiry, data, evidence, the role of what is already known, conclusion driven from data and evidences. No single set of steps or sequences were observed in their investigations, and the teachers reflected on their experiences to link them to NOSI aspects. In this activity, they also discussed general aspects of science such as asking questions, making observations, and developing models and explanations.

In the final sessions, activities that could be carried out in the ateliers (workshop rooms) of the SCs were conducted in an inquiry-based form with NOS and NOSI-rich aspects. At the end, teachers presented their lesson plans and evaluated the modules.

3.4 Data Collection

The views about scientific inquiry (VASI), an instrument developed by Lederman et al. (2014) and adapted to Turkish by Karışan et al. (2017), was used to collect data regarding the teachers' views about scientific inquiry. Karışan et al. (2017) applied VASI to 314 pre-service teachers to validate the Turkish version. In the present study, the VASI, including 7 open-ended items, was administered to the teachers before and after the workshop and was completed in almost 30 min. The time was short between pre-VASI and post-VASI administration because the participants, who came from different parts of the country, were attending these sessions only for a week. Additionally, seven teachers were interviewed at the end of the workshop related to their responses on VASI instrument. Teachers' lesson plans were also evaluated as to whether they embodied NOSI aspects into lesson plans. The teachers prepared these plans working in groups, first when they visited the SC and, then, when the whole workshop was completed. In the lesson plans, the teachers were expected to prepare a plan clarifying what they would do before, during, and after and SC visit.

3.5 Data Analysis

Qualitative data analysis was employed and the researchers used a descriptive content analysis technique (Fraenkel et al. 2012) to analyze the VASI data with the rubric developed by Karışan et al. (2017). This rubric has four categories: uninformed, naïve, transformative, and informed. In order to have reliable results, Krippendorff's alpha (α) was used for intercoder agreement and was calculated as .89. A few of the project team's science education professors analyzed separately 10 teachers' responses to obtain consensus, based on agreements the rest of the responses were analyzed by the authors of this article. The frequencies of the response categories across all items were calculated. The tables provided in the Findings section elaborate how data analysis was transformed from first-order interpretations to second-order interpretations based on the categories provided by Lederman et al. (2014). Researchers also analyzed the responses obtained from the VASI-related interviews conducted with seven teachers. The interview data was compared to teachers' responses to the open-ended essay-type items of the VASI instrument. These data also helped to utilize a holistic approach to evaluate teachers' responses among the items. There was no contradiction among teachers' VASI instrument responses and their interview data. Therefore, the analysis of interviews is not presented here as a separate section. The pre/post lesson plans were analyzed to see the progression of teachers in utilizing SI in their plans. For the analysis of the lesson plans, we used a more analytic procedure: First, the researchers studied the lesson plans, and then generated some categories and themes, later, interpretations were provided.

4 Findings

The findings are presented in the following order: the sample VASI responses and the number of teachers based on categories, and then the analysis of the lesson plans.

4.1 VASI Responses

Table 3 indicates how the responses are categorized as "naive," "transitional," and "informed" for the eight aspects, with item numbers, sample responses, and their categorization. Although in Table 3, specific explanations are linked to categories, a holistic approach is used to analyze the responses given to various aspects of SI. All related items were examined while categorizing a response as "naive," "transitional," or "informed." This means that scoring is not done as a simple one-to-one correspondence between an aspect and a single item.

The responses obtained from the post-VASI were obviously improved compared to pre-VASI. For example, a teacher's responses in pre-VASI and post-VASI about "no single way for scientific investigation" are transformed from transitional to informed view. The statements are provided respectively:

> Scientific investigation may be conducted through quantitative and qualitative observations. In both cases, there are different processes. In investigating the structures of the universe, scientists both do experiment and make observations (A more transitional view).
> In scientific investigations, scientists may use different methods to answer their research questions. Sometimes, they may set an experimental design, and sometimes a different design such as one single observation. Each method of investigation has its own procedures, and using different a method does not mean that they will always reach totally different answers. The difference may be arising from experiences and the cultures of the scientists rather than the methods (A more informed view).

The number of the teachers who held uninformed views about VASI aspects decreased for all items. This result supports the idea that the knowledge required to improve VASI was successfully embedded in the activities throughout the PD workshop. To make it more concrete, while engaging in "Measurement of the Earth's Circumference" teachers usually used the same method in their investigations to answer the guided question. At the end, they came up with different answers. Contrarily, in "Let's Make a Cold Pack" activity, they were free to select their own methods of doing science and reached the same conclusions. At the end of each activity, a brief discussion was carried around NOSI elements embodied in that activity. These discussions were used to help teachers in applying their SI knowledge in situations given in the questionnaire. Teachers did science and conduct investigations through

Table 3 Sample responses for categorization of the aspects of VASI questionnaire

VASI aspect	VASI item	Sample response from science teachers	Categorization
1. Scientific investigations all begin with a question but do not necessarily test a hypothesis	1a	It is only an observation, not a scientific investigation (T9)	Naïve
		Yes, it is a scientific investigation because there are more than one variable (T1)	Transitional
		It is a scientific investigation because there is a question, the data is based on observation and it is consistent with theory of evolution (T23)	Informed
	1b	It is an experiment that based on observation (39)	Naïve
		Based on observation a hypothesis is developed, data is collected through investigation to support hypothesis (T23)	Transitional
		It is not an experiment, but still it is a scientific investigation. In experiments there should be variables (T21)	Informed
	2	I agree with "No," I mean all investigations do not begin with a question (T32)	Naïve
		I think scientific investigations began with questions (T5)	Transitional
		Yes, all investigations began with question(s), scientist investigate to answer these questions through different scientific methods (T11)	Informed
2.There is no single set and sequence of steps followed in scientific investigations	1b	It is an experiment that based on observation (T39)	Naïve
		Based on observation a hypothesis is developed, data is collected through investigation to support hypothesis (T23)	Transitional
		It is not an experiment, but still it is a scientific investigation. In experiments there should be variables (T21)	Informed
	1c	No, in scientific investigation you have followed some certain steps, usually only one method (T28)	Naïve
		Yes, because sometimes both experiments and observation may be employed together (T11)	Transitional
		Yes, there is no single method of scientific investigation, experiments; observations are some of them (T21)	Informed
3.Inquiry procedures are guided by the question asked	5	Group B will collect more data about this experiment (T17)	Naïve
		The independent variable is the brand of wheels, it affects the dependent variable (T12)	Transitional
		Group A's experiment gives better results for testing different, since the independent and dependent	Informed

Table 3 (continued)

VASI aspect	VASI item	Sample response from science teachers	Categorization
		variables are aligned with the question asked (T33)	
4.All scientists performing the same procedures may not get the same conclusions	3a	Yes, they will reach the same conclusion (T8)	Naïve
		No, even they investigate the same question with the same method; they may not come to same conclusions (T11)	Transitional
		Same research question and method of investigation does not mean the same outcomes because scientist may have different observations, perceptions, and culture, it affects the conclusions (T35)	Informed
5.Inquiry procedures can influence the conclusions	3b	No, scientists do not reach the same conclusions since some methods may be far from answer of the investigation (T28)	Naïve
		Though different methods scientist may reach the same conclusions because usually the true is "true" for each data collection method (T22)	Transitional
		Same research question, but different data collection methods may result in the same conclusions provided that the scientists' experiences, perception and cultures will be similar. If not, they may obtain different conclusions (T33)	Informed
6.Research conclusions must be consistent with the data collected	6	Growing of the plants is not related with the sunlight (T19)	Naïve
		Plants' amount of grow is indirectly proportional to amount of sunlight. Based on the given data they grow more when sunlight is less (T8)	Transitional
		Based on the data; plant's grow rate is decreased when the duration of sunlight is increased, this means it grow less when time of sunlight is increased. According to data plants' grow is indirectly proportional to time it exposed to sunlight (T13)	Informed
7.Scientific data are not the same as scientific evidence	4	Data is qualitative or quantitative observations, but evidence is the result of an experiment (T5)	Naïve
		Data and evidence are different, data is collected through the investigation, and evidence is more organized data (T23)	Transitional
		Data and evidence are different, data is collected through the scientific investigation whereas evidences are organization of data to	Informed

Table 3 (continued)

VASI aspect	VASI item	Sample response from science teachers	Categorization
		support or refute the hypothesis or answer the research question or make conclusions (T33)	
8.Explanations are developed from a combination of collected data and what is already known	7a	First model is more functional and bigger (T10)	Naïve
		Based on what is already known about anatomy of majority of animals, directs scientist to draw the first (T12)	Transitional
		Having strong legs for carrying such a huge body is more rational for scientists, additionally the already known systems usually obeys the first drawing (T29)	Informed
	7b	Scientist use proofed information to make explanations (T22)	Naïve
		Scientists collect data through observations and experiments to make explanations (T11)	Transitional
		Scientists make their explanations based on the collected data and the theories; they also compare and contrast their data with the already known concepts (T6)	Informed

Uninformed category is not provided for all aspects since sample responses for this category were empty or irrelevant. A sample response for uninformed category of data and evidence is, "data and evidence are the same things." The letter T and numbers in parenthesis is code numbers for teachers

these sessions. Lederman et al. stated that ""doing science" is seen as a sufficient vehicle to help students "know science"" (Lederman et al. 2014, p. 71); however, such implicit approaches are perceived to be insufficient by many scholars to help teachers and students understand NOS and SI. In the workshops, teachers had the opportunity to do scientific investigations facilitated with inquiry elements and an explicit reflective teaching of SI assisted them for better understanding of SI aspects.

In the pre-VASI, a majority of the teachers held transformative views on the first aspect, which states that scientific investigation begins with a question, but does not need to test a hypothesis. When post responses were analyzed, there was strong evidence that teachers' views had transformed to more informed views. Although Karışan et al. (2017) collected data from pre-service teachers, this result is consistent with their findings. When we look at the items 1a and 1b separately, we notice that there is more improvement in 1b, which questions the views about experiments. This is perhaps because they know experiment was presented in some of their inquiries. Researchers deliberately set explicit-reflective NOS and NOSI teaching as an integral part of the PD program for SCs through varying activities. Perceiving NOSI as a subset of NOS, training teachers on NOS and creating an environment to do scientific inquiry helped to improve participants' views of NOSI aspects. For the second aspect, a majority of teachers held naïve or transformative views in the pre-test (see Table 4). However, for the post-VASI, most of them exhibited transformative or informed views. As to the third aspect regarding their views about the role of questions in the inquiry process, we observed that a relatively small amount of change occurred in their views.

A majority of the participants held transitional or informed views at the beginning, and remained so in the end. As shown in Table 4, the number of teachers with informed views is

Table 4 Number of science teachers categorized as holding uninformed, naive, transformative and informed views across eight aspects of SI

$N = 41$ teachers	1. Begins with a question		2. Multiple methods		3. Procedures are guided by the question asked		4. Same procedures may not get the same results		5. Inquiry procedures influence results		6. Conclusions consistent with data collected		7. Data is not the same as evidence		8. Explanations are developed from data and what is already known	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Uninformed	2	0	5	1	1	0	1	0	3	1	2	1	1	0	5	2
Naive	8	2	12	4	5	3	10	5	15	9	9	3	6	1	5	3
Transformative	16	18	16	21	14	10	21	20	10	11	9	5	15	10	23	20
Informed	15	21	8	15	21	28	9	16	13	20	21	32	18	30	8	16

increased. Related to the fourth aspect, "performing the same procedures may not get the same conclusions," a remarkable number of participants' views improved from naïve and transformative to transformative and informed, respectively. This result is consistent with the findings of Sahin and Deniz (2016), who assessed elementary teachers' understandings of nine NOS aspects after participating in a year-long PD program. The fifth aspect, "inquiry procedure influences the results," also improved in the teachers participating in our study. Similar to the work of Sahin and Deniz (2016), we found that NOS teaching contributed to the teachers' understanding of methods of scientific inquiry. For the sixth aspect, "conclusion based on collected data," a sharp difference was observed. One teacher holding an uninformed view at pre-VASI responded correctly in the post-administration. The highest change in the number of informed teachers occurred about the views on the seventh aspect "data is not the same as evidence." One naïve-viewed teacher's response changed to the statement below in the post-VASI which may be an indicator of an obvious improvement:

> Data are different from evidence. It is collected through scientific investigation, and it may be in raw or any other form. Whereas evidence is a more organized version of data in order to support conclusions and research questions.

For the last VASI aspect, which states that "explanations are developed from data and what is already known," the improvement is not as remarkable as the other aspects. For the post-responses of this aspect, the number of teachers with transformative views was higher than those who held informed views. In post-VASI analysis, informed views about NOSI in the 1st, 3rd, 6th, and 7th aspects were more than the transformative, naïve, and uninformed views. These findings are consistent with those of Karışan et al. (2017). Some of these aspects are described as science process skills, such as asking questions and collecting data. In all types of views, science teachers developed in SI after the PD program. Teachers holding naïve-views may not effectively integrate SCs into school science learning. Gutwill and Allen (2012) support this claim by stating that SI experiences need to be improved for teaching/learning in informal environments.

4.2 Analysis of Lesson Plans about SI

If the teachers' understanding of NOSI has improved, will they include more NOSI elements in their lesson plans designed for an effective SC visit? Will they include SI aspects in lesson plans prepared for SC? Teachers worked collaboratively in their groups on a topic selected from curriculum of grades 5 to 8, and expected to prepare a lesson plan about a visit to the nearest SC. Their lesson plans included three phases: before, during, and after a SC visit, analysis of lesson plans is given in these three phases. In Table 5, participants' post-lesson plan analyses are indicated to provide evidence to support whether they use SI elements. Teachers pre-planned lesson plans were limited only to making observations of exhibits at SCs without a detailed connection to school science. Therefore, we focused on the post-lesson plans to detect SI ideas. Additionally, teachers were not instructed to use SI aspects in the lesson plans, and the plans were prepared for an effective SC visit. They were only asked to plan lessons with three phases. As seen from Table 5, all groups prepared their plans for grade levels 7 and 8. One reason for that may be that a majority of participants were teaching in these grade levels. The second reason may be that concepts/topics in these levels are related to the SC facilities more easily.

Table 5 Details regarding teachers' post-lesson plans designed for an SC visit

Group no.	Content and objectives	Grade level	Science processes, methods of inquiry	NOSI aspects	Teaching methods	Related exhibit in SC
1	Light and sound -Speed of sound -Energy of light	7	Questioning, observation, data collection, evidence, justification, prediction, explanation	Questions guide inquiry, procedures are guided by asked question, inquiry procedure can influence conclusions, conclusions must be consistent with data, explanations are developed from collected data.	Argumentation inquiry-based teaching, POE	Energy and sound exhibit, experiments, the ring in vacuum
2	Sound	8	Questioning, observation, explanation	Questions guide inquiry	Argumentation POE	Sound exhibit
3	Optic	7	Questioning, observation, explanation	Questions guide inquiry	Argumentation inquiry	Concave/convex mirrors, colors, cartoons machine
4	Optic, mirrors	7	Questioning, observation, explanation, claim, data, justification, rebuttal, critical thinking, evaluation,	Questions guide inquiry, procedures are guided by asked question, inquiry procedure can influence conclusions, conclusions must be consistent with data, explanations are developed from collected data.	Inquiry, argumentation, POE, cooperation	Periscope
5	Optic, mirrors	7	Questioning, observation, prediction, data collection, claim, justification, rebuttal, evidence, evaluation	Questions guide inquiry	Inquiry-based argumentation STEM	Kaleidoscope
6	Mirrors, mirror types	7	Questioning, observation, explanation	No scientific inquiry in SC	Cooperation inquiry	–
7	Types of mirrors, their use in daily life, reflection in mirrors	7	Questioning, prediction observation, data collection, experiment, manipulation of variables	Questions guide inquiry, procedures are guided by asked question, same procedures may not get the same the same results, inquiry procedure can influence conclusions, conclusions must be consistent with data, explanations are developed from collected data.	POE inquiry	Periscope, kaleidoscope, concave/convex mirrors, illusions, anamorphic, flying mirror, praxinoscope

STEM, Science-Technology-Engineering-Mathematics; *POE*, predict; observe, explain

4.2.1 Parts of Lesson Plans about "Before an SC Visit"

Teachers usually wrote that they would call the nearest SC and obtain details about the exhibits and the ateliers available. Some groups stated that they would visit a SC without students prior to an actual trip in order to categorize the exhibits based on the presented topic in the curricula. One group also mentioned that they would do a search about the exhibits and other facilities of the SCs by keeping in touch with explainers for collaboration. They also stated that they would measure their students' prior knowledge first, and then link the course objectives to the related exhibits. The seventh group explained that students' inquiries would begin with in-class activities. Teachers would present an enclosed box with a hole at the top and ask the students to look through the hole before the SC visit. Additionally, some utensils such as plane mirrors, cardboards, aluminum plates, tea spoons, papers, scissors, and glue would be given to students in order to model the given box. The actual design of the box would not be presented to the students prior to the SC visit. Then, the students would be directed to the related exhibits to answer certain questions.

4.2.2 Parts of Lesson Plans about "During an SC Visit"

Groups selected a unit from the curricula and they matched concepts with the appropriate exhibits. For example, the first group selected the topic of "Light and Sound," stating that students would work in groups in the SC to investigate a pre-determined research question. In the lesson plan, the teachers asked "why don't humans on Earth hear the sound of explosions in the space?" Providing the list of "Light-Sound" related exhibits to the students, the teachers assumed that the groups would spend time inquiring about these concepts among the exhibits. Guiding their students to the exhibit called "A Bell in A Bell Jar" was assumed to be the place where groups' investigations would be conducted since this exhibit provides opportunity to test sound of a bell in vacuum. The teachers expected students to make observations and write a report on sheets already provided to them. A bell could be heard ringing within a bell jar connected to a vacuum pump. When the system was switched on, the air is slowly removed and the intensity of the sound would decrease. The teachers noted that once vacuum was achieved, students would hear no voice. Then the system would be switched off and air would be allowed to re-enter the bell jar slowly. During this process, students were expected to collect data and make inferences about their inquiry. The teachers wrote in their plans that the students would make explanations based on the changes observed in the "A Bell in A Bell Jar" exhibit to reach the conclusion that sound cannot spread in space. According to the provided explanations in the lesson plan, it is evident that the teachers used SI: students' inquiry would start with a question and would be guided by it. The teachers' explanations and assumptions about students works and talks in their lesson plans also showed that the NOSI aspects "inquiry procedures influence conclusion," "conclusions must be consistent with the collected data," and "explanations are developed from collected data" were also used. In the explanations provided in the lesson plans of this group, rather than referring to the names of these aspects, the sentences referred to the existence of other aspects. This means that the provided explanations imply that the group was aware of certain NOSI aspects and included them in a plan for a SC visit. In the lesson plans of the first group, there was no sign of NOSI aspects regarding "no single set of sequences in inquiry," "same procedures may not get the same result," and "data is not the same with evidence."

In the lesson plan of the third group, there was the question "How does the cartoon machine work?" However, there was no explanation regarding what students would inquiry about, or how teachers would guide the procedure. Asking this question without any further elaboration is an indication of teachers' awareness that inquiry procedures start with a question. The lesson plan of group seven included at least two questions related to exhibits concerning "mirrors." A group of students were led to the concave/convex/plane mirrors, another to periscope and kaleidoscope, others to the anamorphic, flying mirror, and the praxinoscope in order to answer some pre-determined questions. Students were expected to keep two plane mirrors at different angles and observe the number of images formed. Teachers assumed that they would guide students to investigate the number of images when the angle between two plane mirrors was at 180°, 120°, 90°, 60°, and 0° and then record their observations. These explanations are indicators of the teachers' use of NOSI aspects, stating that inquiry starts with a question and the process is guided by it. Additionally, the NOSI aspects' "same procedures may not get the same results," "inquiry procedures influence conclusion," "conclusions must be consistent with the collected data," and "explanations are developed from collected data" were also provided in the lesson plan. The seventh group's lesson plan also included the NOSI aspect "the same procedure may not get the same result," which is different from the first group's lesson plan. Teachers stated that they would ask students why multiple images were formed in some cases, assuming that some would explain it by stating that the image of an object formed in one plane mirror would act as an object for the other plane mirror, and others providing alternative explanations. This statement is an indication that carrying out the same inquiry process may not yield the same result. Teachers stated in their plans that at the end of the inquiry on plane mirror, the groups would reach the conclusion "As the angle between the two plane mirrors decreases, the number of images formed increases." This statement can be related to the NOSI aspect concerning "explanations are developed from collected data."

4.2.3 Parts of Lesson Plans about "After an SC Visit"

A majority of groups stated that they would use different kinds of assessment tools for monitoring students' cognitive and affective gains when they returned to their school. Group wanted students to prepare posters about their visits. Group seven stated that when students returned to their school, the models designed before the SC visit would be given back to them for improving them. After the design process, the students were also directed to do an inquiry in order to answer the question "How would you change the size of image to a bigger or smaller format?" The NOSI aspects "no single set of sequence, steps in inquiry" and "data is not the same with evidence" were not detected in the participants' lesson plans. Although from the statements of some groups, it can be inferred that the explanations are developed from collected data, the notion "what is already known" is not mentioned for this aspect.

While evaluating the lesson plans, we noticed that NOSI aspects were observed in teachers' explanations, but not stating the names of the aspects apparently. Whereas, their use of methods of inquiry-based teaching, science processes (e.g., prediction, explanation), and methods of inquiry (e.g., observation, experimentation) was obvious in the lesson plans. In the "New Society" activity, the teachers engaged in an observation process, made predictions, acted like scientists and tried to grasp how scientists made decisions based on the empirical evidence they collected. The consensus NOS tenets, except for the one related to theory-law, were all covered. Although, how creativity, imagination, and subjectivity affect scientific inquiry had already been discussed, the teachers neglected to provide explanations about the knowledge acquired and about the process of scientific inquiry. In "Let's Make a Cold Pack" activity using an argument-driven inquiry, some teachers argued for certain claims and others argued against other claims with their justifications referring to how scientists did science. Lesson plans also reflected participants' gains from the workshop in terms of using inquiry-based methods of teaching. It was evident that the transmission of inquiry into lesson plans was primarily mediated by teachers' understanding of newly acquired inquiry-based teaching methods (i.e., the argument-driven inquiry and POE activities) possibly because they had just practiced these methods through hands-on and minds-on activities. Posing questions, creating a feeling of possessing inadequate knowledge on the topic, and so initiating inquiry were the mainly used scientific practices during scientific investigations. Teachers' understanding of NOSI was embedded into their use of inquiry-based teaching methods in the SCs. The elements posing questions, designing investigations, and generating evidence were also their understanding of NOSI. Moreover, collecting data, creating evidence to explain results and drawing conclusions were also used clearly. The lesson plans were considered as reflections of teachers' scientific inquiry interactions in the context of SCs.

When comparing the responses obtained from the VASI instrument with the details of lesson plans, we observed that the more teachers improved on their VASI views, the more details of SI were provided in their lesson plans. The groups with more informed teachers prepared more NOSI-rich lesson plans in SCs with more orientations of engaging students in more methods of scientific inquiry such as experimentation. The inquiry concepts concerning methods of scientific inquiry; questioning, observation, and explanation were used by all groups. In this context, "no single step of SI" and "data are not the same with evidence" were used. This may be because the items were epistemic in nature. Based on the lesson plans, we can say that in SCs, some teachers may have done less well in guiding their students to utilize inquiry as a scientific practice, whereas others could better guide students by employing SI in SCs to do scientific practices as a teaching/learning activity.

5 Discussion and Conclusions

Understanding about scientific inquiry is a critical element of teachers' professional development (PD) to better utilize science centers (SCs). In this study, we investigated the impact of a PD program designed for elementary science teachers in order to effectively integrate SCs and formal school curricula. In particular, NOS, NOSI, inquiry-based teaching methods, process skills, and teaching/learning with/in SCs were embodied within the activities of the PD modules. Designing experimental set-ups modeling SC exhibits, developing activities using ateliers of SCs, and designing integrated lesson plans for SC-school curricula were the unique aspects of this PD model. Many original activities were developed to support in-service teachers. In almost all modules, teachers engaged in inquiry-based strategies. This article specifically investigated the improvement in NOSI and how SI aspects, inquiry-based teaching methods, and methods of scientific inquiries were used in lesson plans prepared for a SC visit.

Based on lesson plans, we noticed that even though teachers regarded their methods of teaching as inquiry-based, still some could not sufficiently guide their students to do scientific inquiry in SCs. Assuming the reflected issues in the lesson plans prepared for teaching with/in SCs, the PD program obliviously helped teachers to effectively organize a visit to SCs to support school learning. Although the improvement is evident from pre-VASI to post-VASI and from pre-lesson plans to post-lesson plans, there is still enough room for development in terms of views of NOSI and, consequently better use of scientific inquiry by teachers in the future in SCs. Briefly, it can be stated that a thorough use of SI in lesson plans was not observed, one reason for that may be inadequate development in the teachers' PCK components such as pedagogical knowledge and knowledge of context. According to Magnusson et al. (1999), teachers PCK stems from the integration of different kinds of knowledge; knowledge of curriculum, learners, instruction, and assessment, as well as their orientations toward science teaching. Moreover, these are influenced by the context. Magnusson et al. (1999) described PCK as a transformation of subject matter knowledge, pedagogical knowledge, and knowledge of context. In the present case, teachers are fostered about pedagogical knowledge and knowledge of context. Although the photographs and desktop applications of some exhibits were usually used in the entire workshop, spending only a few hours (one half-day) at SCs may be considered as a possible lack of learning of the context. Spending much more time with each exhibit could make teachers more knowledgeable about these contexts, and so improve them more about their PCK components. Another reason for not enough SI integration may be that the teachers were not clearly instructed to use SI or NOS in their plans, and that they were only expected to design a lesson plan for an effective SC visit with before, during, and after visit phases. In other words, if teachers had been directly instructed to use SI, such an instruction might have served as demand characteristic which means that directions would be subtle cue that might make teachers aware of what the researchers expect. In such a case, the use of SI in lesson plans would be different because teachers might alter their use of SI to conform to expectations. As stated before, compared to the pre-lesson plans, the post-lesson plans were significantly improved concerning SI aspects. When focusing on all SI aspects in these plans, only two groups were able to utilize SI properly without guidance.

Teachers' views about scientific inquiry obtained from VASI were similar to those of pre-service teachers as reported by Karışan et al. (2017) before the workshop. When only questionnaire outcomes are considered, the results indicate that the modules were effective in improving their views about SI. At the post-administration, the number of uninformed and naive views decreased, that of transformative views increased compared to naïve or uninformed, whereas that of informed views also increased. Some of the teachers could also reflect SI practices in their lesson plans. Although it is difficult to see clearly different aspects of views about SI in lesson plans, guiding students' inquiry, posing questions, collecting data, making observations and some detailed explanations were the used NOSI aspects.

Based on the applied teaching methods, there is evidence that teachers' orientations shifted to more constructivist practices, which are milestones for effectively using SCs as a teaching environment. During the first sessions of the workshop, teachers' orientations in SCs were elicited in order to make them feel dissatisfied with these orientations. The intelligibility of new orientations that support integration of SI in SC teaching practices was enhanced. Another gain among the teachers was using the inquiry element or methods of scientific inquiry in SCs as reflected in their lesson plans. One reason for this may be that they have heavily encountered these concepts during the workshop. Another reason may be the content of teacher education programs in the country of the study. Pre-service science teachers were expected to have developed science process skills when they completed their degrees. Skills such as investigating, problem solving, hypothesizing, observing, questioning, experimenting, and manipulation of apparatus and materials are usually mentioned in teacher preparation programs and, thus, may be reflected in their lesson plans for SCs. However, even though some science process skills and SI practices were provided in the lesson plans, it was rare to detect statements in the same way as the aspect is described. The aspects included in the VASI instrument are more epistemic, but the lesson plans are action-oriented in SCs. Additionally, another possible reason for this can be the nature of the VASI instrument since it is about the role of questions, observation, and experiments in scientific investigations, the effect of the inquiry process over the results and conclusion, and differences of data and evidences. Although some tenets of NOSI measured by VASI aspects were explicitly developed through the workshop, and scientific inquiry practices were generally embedded in the lesson plans, one may not claim with certainty that these measures were actually put into use within the actual settings in SCs.

Lederman et al. (2014) have stated that "VASI will allow researchers to explore many of the long standing assumptions regarding understandings about SI that are presumed similar to understandings about NOS" (p. 80). Our findings are in agreement with Lederman's claim; although teachers prepared their lesson plans in groups, we found similar outcomes with Abd-El-Khalick et al. (1998), who found a lack of NOS elements in pre-service teachers' lesson plans. However, the context of Abd-El-Khalick et al. (1998) is not the same with our work, but they still stated that "lesson plans showed rare evidence of planning to teach the NOS" (p. 426). Their study also confirmed the necessity of explicit instruction about these concepts. Accordingly, we have evidence of similarities in the understanding of NOS, which is reported in the literature, and SI as in our study. In our case, teachers did scientific inquiry in almost all activities, and thus NOSI may have been more at focus. NOS, on the other hand, may be viewed as less significant than other instructional outcomes for teachers (Abd-El-Khalick et al. 1998); this may also be valid for NOSI. Abd-El-Khalick et al. (1998) also stated that teachers' discomfort with their own understanding of NOS elements, and lack of experience in teaching NOS impact their practices. In this case, lack of planning time and lack of knowledge about teaching specific science content with the facilities of SCs and utilizing from a new context (SC) may hinder proper use of SI concepts. Abd-El-Khalick et al. (1998) additionally stressed the existence of a complex interaction between teachers' perspectives on NOS, pedagogy, and instructional outcomes which affect their use NOS. Similar to their views, Aydın et al. (2013) also focused on the necessity of both a strong understanding of NOS and PCK for teaching NOS. Thus, we may also claim similar requirements for understanding of NOSI and using SI in lesson plans, that is, teachers' are required to have strong understanding of NOSI and they should be fostered enough to improve their PCK related components such as knowledge of context that impact the use of SI in SCs. Among the seven groups, only two prepared lesson plans reflected teaching in SCs and contained SI elements. Although teachers were free to select any of the exhibits, another possible reason that hinder thorough use of SI may be that each exhibit at the SC might not have intrigued teachers to do inquiry, or that teachers might not have felt confident with the topic or learning environment. After all, the context was new and a majority of the participants were not experienced in effectively using SCs. Therefore, we suggest further works to focus on allowing teachers to spend more time and do more SI at SCs. In addition, as seen from Table 5, some groups tended to focus more on exhibits in SCs that were more similar to their topics at school. Furthermore, NOS/NOSI as a whole may not have to be necessarily included in each science topic.

Lederman (1998) described the "Black Box" activity as proposing investigations that allow explicit treatment of scientific inquiry. The "Let's Make a Cold Pack" activity supported engagement in SI practice; through argument-driven inquiry, teachers experienced the SI elements as well as particular NOS aspects. Throughout different activities, NOSI was explicitly taught and teachers did scientific inquiry. Although we did not guide the teachers about the integration of NOS and NOSI in their lesson plans, and we did not even propose to measure NOS, we observed that the teachers' use of SI in SC-oriented lesson plans included much more SI than NOS. Reflecting upon the participants' lesson plans for teaching in SCs, we can state that they mainly improved in using science process and the methods of science. However, using a fixed set and sequence of steps that all students follow while attempting to answer the guided questions may be interpreted as teachers' persisting tendency to use the traditional methods of science. Even though an obvious improvement was observed in VASI concerning no single fixed set or sequence of steps that all scientific investigations follow, this was not clearly reflected in their lesson plans. The presence of inquiry elements, such as science process and methods of science in SC lesson plans, can also be attributed to the effect of the workshop on transforming teachers' views from empiricist/traditional to more constructivist ones. According to Tsai (2007), empiricist/traditional-oriented teachers tend to use traditional strategies, whereas, constructivist ones use more constructivist strategies. As a whole, the workshop may have had an influence over the teachers' use of constructivist strategies perceived to be necessary for informal science learning environments.

The lesson plans of most groups included science processes and process skills, as is evident in Table 5. SI goes beyond a simple development of process skills such as observing, inferring, classifying, predicting, measuring, questioning, interpreting and analyzing data. We observed that the participants' scientific inquiry was made up not only of traditional science processes, but also that they combined these processes with scientific knowledge, scientific reasoning, and critical thinking in order to develop scientific knowledge. Researchers' analytical memos are in agreement about teachers' awareness on NOS and NOSI tenets. The explanations derived from the lesson plans for SCs may infer that scientific knowledge is empirical: that it is based on and/or derived from observations. Teachers used these elements in their scientific inquiries without any explicit instruction from the researchers, and the role of observations and inference in scientific knowledge had a more prominent presence in their plan-based investigations. The place of social and cultural roles over scientific investigations and scientific knowledge were not evident from SC-related lesson plans. As Erdoğan and Köseoğlu (2015) and Lederman (1998) suggested, we used explicit-reflective NOS and NOSI instruction by integrating their aspects within specific activities. Measurement tools, VASI, and lesson plans indicated different outcomes; a majority of teachers did not reflect use of SI aspects thoroughly in their lesson plans for SCs; however, they seemed to be more competent in their views about SI according to VASI analysis.

According to Vhurumuku (2015), many teachers fail to teach about NOSI because they either do not understand it or lack the pedagogical skills to teach about it. Abd-El-Khalick and Lederman (2000) have suggested an explicit instruction to enable teachers to teach effectively about NOSI. An explicit-reflective instruction was used in the workshop. One reason that there were few NOSI aspects in the lesson plans was the limited time during which the lesson plans were prepared. The time spent at SC was also limited; teachers had restricted experiences related to teaching in SC with scientific inquiry. According to Garcia-Carmona and Acevedo-Diaz (2018), nature of scientific practice is a subset of NOS and there exist several didactic approaches for what and how to teach NOS; however, there are limited plans for teaching of science that is inspired by real scientific practices. Based on lesson plans, there are evidences to claim that some teachers plan to teach science in SCs by doing real scientific inquires along with proving opportunity for students to learn the nature of scientific inquiry. This indicates that some teachers' views about teaching science and NOSI have changed. Through the present study, there are also evidences to state that teachers' views about scientific inquiry were enhanced and their repertoires of inquiry-based teaching methods were improved.

No work has been published on the effect of a PD related with in-service science teachers' views about scientific inquiry and their lesson plans for teaching in SCs. Many participating teachers in the present study had at least 10 years of experience in teaching, which implies that the current aspects of scientific inquiry may not have been comprehensively integrated into the courses when they were pre-service teachers within the context of the present study. This shows the need to integrate NOSI aspects into professional development programs. Wahbeh and Abd-El-Khalick (2014) worked with teachers on their NOS understanding and classroom practices, revealing that practices are affected by NOS understandings, which are situated within the science contents, contexts, and experiences. They stated that these three aspects limit teachers' abilities to transfer their understandings into novel contexts and contents. Designing lesson plans that are restricted to a science content in a new context (science centers), and currently gained experiences in NOS and NOSI aspects may have limited teachers' views about scientific inquiry based on their lesson plans for SCs. Blue (2018) has assessed students' views about the nature of scientific inquiry through their reflections about science and scientists. The participants wrote their arguments in a familiar context over which they held discussions. In this study, new contents, contexts, and quite new experiences may have restricted participants' use of sufficient inquiry-based investigation for teaching in SCs. Therefore, further studies are needed to develop fruitful lesson plans that embody real scientific inquiries by which teachers can encourage their students to learn about the nature of scientific inquiry in SCs as a new context.

The conclusions drawn from this study are limited to this research context. It may be a limitation to assume that the use of NOSI aspects in lesson plans is also an indication of actually teaching about NOSI in SCs. Following the teachers in SCs with students would be necessary in order to confirm our findings. In a separate article currently under development, the authors have observed a number of teachers during a visit to a SC. The activities performed during the workshop helped some teachers to plan for their students to carry out scientific inquiry in SCs, but not all teachers were able to fully integrate SI in SCs. Although the workshop helped teachers to develop better lesson plans, if the PD workshop had been totally carried out at SCs it might have changed the way their lesson plans turned out. Studies commonly reveal that inquiry skills as well as NOS beliefs can be influenced through educational processes in short time periods, that is a few weeks (Khishfe and Abd-El-Khalick 2002). Despite the short duration of the present study, we also observed changes in teachers' views and use of scientific inquiry. The time span between pre- and post-assignments was only 5 days, which means that one may consider the impact of testing effect on the findings. However, the items of VASI were not recall-type, lesson plans were open-ended issues, and interviews were conducted for data triangulation, all of which has been carried out to minimize the testing effect.

In line with the missing aspects of NOSI in lesson plans in this study, Pedretti (2002) stated that scientific practices and NOS are usually neglected at hands-on displays of SCs. Additionally, a disconnection between teachers' plans and their actual practices has been documented in the literature. Being aware of all these issues, experiences, and empirical evidence collected throughout this 3-year lasting project, we transformed the PD program in the course of time. One of the transformations was about mentoring teachers for better utilization of informal environments with NOS and NOSI issues. Volunteer teachers continued to be in communication with the project team, they were guided for a long time and they were followed in informal environments. They planned better lessons and practiced effective teaching with/in SCs. Even though this study does not aim to observe teachers in SCs, as a requirement of an effective PD we observed some of the teachers. Based on the analytical memos of researchers and talks with teachers, it is worth mentioning that a 5-day PD workshop was helpful in increasing science teachers' understanding of SI and awareness of employing SI concepts in SCs, as testified by the participant themselves. Since we further observed a few teachers during their SC visit about their use of NOS and NOSI aspects, and mentored volunteers for how to put NOSI into their teaching with/in SCs and how to do SI by embodying related elements in the content and contexts provided in SCs, we need to mention that for fruitful teaching with/in SCs, long-term mentoring is quite effective.

The scope of this study is limited to in-service science teachers' understanding of SI and whether SI concepts are reflected in lesson plans prepared by groups for an effective SC visit. We observed notable positive changes in both issues. Although one may state that only two groups' lesson plans contained SI properly, it can also be stated that other groups' plans also included some SI aspects; moreover, the initial lesson plans had almost no SI components. Further studies are also suggested to follow teachers in the long run during their SC visit with their students regarding their discourses on scientific knowledge and practices. This work provides enough evidence to state that the participants' views about SI were improved, and that their use of inquiry elements in lesson plans which are essentials in teaching in SCs are also improved despite the fact that the lesson plans of five groups lacked proper integration of all SI aspects for teaching in SCs. To foster the development of teachers into the amalgam that is professional development for SCs, they need inquiry-based pedagogies and sufficient understanding of SI for teaching of science to be in line with real scientific practices. In this way, science teachers are more likely to encourage their students to learn about the nature of scientific practice at the same time as learning science in different learning environments such as science centers.

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Conflict of Interest The authors declare that they have no conflict of interest.

References

Abd-El-Khalick, F., & Lederman, N. G. (2000). Improving science teachers' conceptions of nature of science: a critical review of the literature. *International Journal of Science Education, 22*(7), 665–701.

Abd-El-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education, 82*(4), 417–436.

Abell, S. K. (2007). Research on science teacher knowledge. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of Research on Science Education*. Mahwah: Lawrence Erlbaum Associates Publishers.

Adams, J. D., & Gupta, P. (2017). Informal science institutions and learning to teach: an examination of identity, agency, and affordances. *Journal of Research in Science Teaching., 54*(1), 121–138.
Akerson, V. L., & Donnelly, L. A. (2008). Relationships among learner characteristics and preservice elementary teachers' views of nature of science. *Journal of Elementary Science Education, 20*(1), 45–58.
Allchin, D. (2011). Evaluating knowledge of the nature of (whole) science. *Science Education, 95*, 518–542.
Astor-Jack, T., McCallie, E., & Balcerzak, P. (2007). Academic and informal science education practitioner views about professional development in science education. *Science Teacher Education, 91*(4), 604–628.
Avraamidou, L. (2015). Reconceptualizing elementary teacher preparation: a case for informal science education. *International Journal of Science Education, 37*(1), 108–135.
Avraamidou, L., & Zembal-Saul, C. (2010). In search of well-started beginning science teachers: Insights from two first-year elementary teachers. *Journal of Research in Science Teaching, 47*(6), 661–686.
Aydın, S., Demirdöğen, B., Muslu, N., & Hanuscin, D. L. (2013). Professional journals as a source of PCK for teaching nature of science: an examination of articles published in The Science Teacher (TST) (anNSTAJournal), 1995–2010. *Journal of Science Teacher Education, 24*(6), 977–997.
Bianchini, J. A., & Colburn, A. (2000). Teaching the nature of science through inquiry to prospective elementary teachers: a tale of two researchers. *Journal of Research in Science Teaching, 37*(2), 177–209.
Blue, J. (2018). Assessing astronomy students' views about the nature of scientific inquiry. *Physical Review Physics Education Research, 14*(1).
Burgin, S. R., & Sadler, T. D. (2016). Learning nature of science concepts through a research apprenticeship program: a comparative study of three approaches. *Journal of Research in Science Teaching, 53*(1), 31–59.
Bybee, R. W. (2000). Teaching science as inquiry. In J. Minstrell & E. H. van Zee (Eds.), *Inquiring into Inquiry Learning and Teaching in Science* (pp. 20–46). AAAS: Wanshignton, DC.
Cavallo, A. (2008). Experiencing the nature of science: An interactive, beginning-ofsemester activity. *Journal of College Science Teaching, 37*(5), 12–15.
Chang, Y. H., Chang, C. Y., & Tseng, Y. H. (2010). Trends of science education research: an automatic content analysis. *Journal of Science Education and Technology, 19*, 315–331.
Cox-Petersen, A., Marsh, D. D., Kisiel, J., & Melber, L. M. (2003). An investigation of guided school tours, student learning, and science reform: Recommendations at a museum of natural history. *Journal of Research in Science Teaching, 40*, 200–218.
Crawford, B. (2014). From inquiry to scientific practices in the science classroom. In N. Lederman & S. Abell (Eds.), *Handbook of research on science education, vol. II* (pp. 515–544). New York: Taylor and Francis Group.
Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young people's images of science*. Buckingham: Open University Press.
Eick, C., & Reed, C. (2002). What makes an inquiry-oriented science teacher? The influence of learning histories on student teacher role identity and practice. *Science Education, 86*, 401–416.
Erdoğan, M. N., & Köseoğlu, F. (2015). Explicit-reflective instruction of nature of science as embedded within the chemical equilibrium. *Journal of Theory and Practice in Education, 11*(2), 717–741.
Erduran, S., & Dagher, Z. R. (2014). *Reconceptualizing the nature of science for science education: Scientific knowledge, practices and other family categories*. Dordrecht: Springer.
Feinstein, N. W., & Meshoulam, D. (2014). Science for what public? Addressing equity in American science museums and science centers. *Journal of Research in Science Teaching, 51*, 368–394.
Fraenkel, J., Wallen, N., & Hyun, H. (2012). *How to design and evaluate research in education* (8th ed.). Columbus: McGraw-Hill Higher Education.
Garcia-Carmona, A., & Acevedo-Diaz, J. (2018). The Nature of scientific practice and science education. *Science & Education, 27*(5–6), 435–455.
Gutwill, J. P., & Allen, S. (2010). Facilitating family group inquiry at science museum exhibits. *Science Education, 94*, 710–742.
Gutwill, J. P., & Allen, S. (2012). Deepening students' scientific inquiry skills during a science museum field trip. *Journal of the Learning Sciences, 21*(1), 130–181.
Irzik, G., & Nola, R. (2011). A family resemblance approach to the nature of science. *Science & Education, 20*, 591–607.
Kampourakis, K. (2016). The "general aspects" conceptualization as a pragmatic and effective means to introducing students to nature of science. *Journal of Research in Science Teaching, 53*(5), 667–682.
Karışan, D., Bilican, K., & Şenler, B. (2017). Bilimsel Sorgulama Hakkında Görüş Anketi: Türkçeye Uyarlama, Geçerlik ve Güvenirlik Çalışması. *İnönü Üniversitesi Eğitim Fakültesi Dergisi, 18*(1), 326–343.
Kelly, J. (2000). Rethinking the elementary science methods course: a case for content, pedagogy, and informal science education. *International Journal of Science Education, 22*(7), 755–777.

Khishfe, R., & Abd-El-Khalick, F. (2002). Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science. *Journal of Research in Science Teaching, 39*(7), 551–578.

Leblebicioglu, G., Metin, D., Capkinoglu, E., Cetin, P. S., Eroglu, D. E., & Schwartz, R. (2017). Changes in students' views about nature of scientific inquiry at a science camp. *Science & Education, 26*(7–9), 889–917.

Lederman, N. G. (1998). The state of science education: subject matter without context. *Electronic Journal of Science Education, 3*(2), 1–6.

Lederman, N. G. (2007). Nature of science: past, present and future. In S. A. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 831–879). Mahwah: Lawrence Erlbaum Associates.

Lederman, J. S. (2009). Teaching scientific inquiry: Exploration, directed, guided, and opened-ended levels. In *National geographic science: Best practices and research base* (pp. 1–5). Hampton-Brown Publishers.

Lederman, N. G. (2019). Contextualizing the Relationship Between Nature of Scientific Knowledge and Scientific Inquiry. Science & Education (this volume). https://doi.org/10.1007/s11191-019-00030-8.

Lederman, N. G., & Abd-El-Khalick, F. (1998). Avoiding de-natured science: Activities that promote understanding of the nature of science. In W. McComas (Ed.), *The nature of science in science education: Rationales and strategies* (pp. 83–126). Dordercht: Kluwer Academic.

Lederman, J. S., Lederman, N. G., Bartos, S. A., Bartels, S. L., Meyer, A. A., & Schwartz, R. S. (2014). Meaningful assessment of learners' understandings about scientific inquiry—The views about scientific inquiry (VASI) questionnaire. *Journal of Research in Science Teaching, 51*(1), 65–83.

Loucks-Horsley, S., Stiles, K. E., Mundry, S., Love, N., & Hewson, P. W. (2010). *Designing professional development for teachers of science and mathematics* (3rd ed.). Thousand Oaks: Corwin.

Loughran, J., Mulhall, P., & Berry, A. (2003). In search of pedagogical content knowledge in science: Developing ways of articulating and documenting professional practice. *Journal of Research in Science Teaching, 41*(4), 370–391.

Luehmann, A. L., & Markowitz, D. (2007). Science teachers' perceived benefits of an out-of-school enrichment programme: identity needs and university affordances. *International Journal of Science Education, 29*(9), 1133–1161.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. Lederman (Eds.), *Examining pedagogical content knowledge: the construct and its implications for science education* (pp. 95–132). Dordrecht: Kluwer Academic.

Matthews, M. (2012). Changing the focus: From nature of science (NOS) to features of science (FOS). In M. S. Khine (Ed.), *Advances in nature of science research* (pp. 3–26). Dordrecht: Springer.

McComas, W. F. (1998). The principal elements of the nature of science: dispelling the myths. In W. F. McComas (Ed.), *The nature of science in science education: rationales and strategies* (pp. 53–70). Dordrecht: Kluwer.

Monteiro, B. A. P., Martins, I., de Souza Janerine, A., & de Carvalho, F. C. (2016). The issue of the arrangement of new environments for science education through collaborative actions between schools, museums and science centres in the Brazilian context of teacher training. *Cultural Studies of Science Education, 11*, 419–437.

Mundry, S., & Loucks-Horsley, S. (1999). Designing professional development for science and mathematics teachers: decision points and dilemmas. *National Institute for Science Education (NISE) Brief, 3*(1), 1–7.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.

National Research Council. (2000). *Inquiry and the national science education standards*. Washington, DC: National Academy Press.

National Research Council. (2009). *Learning science in informal environments*. Washington, DC: The National Academies Press.

National Research Council. (2011). *A framework for K-12 science education: practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

Neuman, W. (2014). *Social research methods: qualitative and quantitative approaches*. Essex: Pearson.

Pedretti, E. (2002). T. Kuhn meets T. Rex: Critical conversations and new directions in science centres and museums. *Studies in Science Education, 37*, 1–42.

Sahin, E. A., & Deniz, H. (2016). Exploring elementary teachers' perceptions about the developmental appropriateness and importance of nature of science aspects. *International Journal of Environmental & Science Education, 11*(9), 2673–2698.

Schwartz, R. S., Lederman, N., Khishfe, R., Lederman, J. S., Matthews, L., & Liu, S., (2002) Explicit/reflective instructional attention to nature of science and scientific inquiry: Impact on student learning. In Paper presented at the 2002 annual international conference of the association for the education of teachers in science. Charlotte, NC.

Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education, 88*(4), 610–645.

Schwartz, R. S., Lederman, N. G., & Lederman, J. S. (2008). *An instrument to assess views of scientific inquiry: the VOSI questionnaire*, National Association for Research in Science Teaching, March 30–April 2, 2008. Baltimore, U.S.

Schwartz, R., Lederman, N., & Abd-El-Khalick, F. (2012). A series of misrepresentations: a response to Allchin's whole approach to assessing nature of science understandings. *Science Education, 96*(4), 685–692.

Senler, B. (2015). Middle school students' views of scientific inquiry: an international comparative study. *Science Education International, 26*(2), 166–179.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*, 4–14.

Smith, W. S., McLaughlin, E., & Tunnicliffe, S. D. (1998). Effect on primary level students of in-service teacher education in an informal science setting. *Journal of Science Teacher Education, 9*(2), 123–142.

Tsai, C. C. (2007). Teachers' scientific epistemological views: The coherence with instruction and students' views. *Science Education, 91*(2), 222–243.

Vázquez-Alonso, Á., García-Carmona, A., Manassero-Mas, M. A., & Bennassar-Roig, A. (2013). Science teachers' thinking about the nature of science: a new methodological approach to its assessment. *Research in Science Education, 43*(2), 781–808.

Vhurumuku, E. (2015). Pre-service teachers' beliefs about scientific inquiry and classroom practices. *International Journal of Educational Sciences, 10*(2), 280–286.

Wahbeh, N., & Abd-El-Khalick, F. (2014). Revisiting the Translation of Nature of Science Understandings into Instructional Practice: Teachers' nature of science pedagogical content knowledge. *International Journal of Science Education, 36*(3), 425–466.

Yu, J. C., & Yang, H. J. (2010). Incorporating museum experience into an in-service programme for science and technology teachers in Taiwan. *International Journal of Technology and Design Education, 20*(4), 417–431.