Res Sci Educ (2016) 46:575–612
DOI 10.1007/s11165-015-9472-z

# Development and Nature of Preservice Chemistry Teachers' Pedagogical Content Knowledge for Nature of Science

**Betül Demirdöğen**[1] **· Deborah L. Hanuscin**[2] **·**
**Esen Uzuntiryaki-Kondakci**[3] **· Fitnat Köseoğlu**[4]

Published online: 11 June 2015


**Abstract** The purpose of this case study is to delve into the complexities of the early development of preservice chemistry teachers' science teaching orientations, knowledge of learners, knowledge of instructional strategies, and knowledge of assessment during a two-semester intervention designed to enhance their pedagogical content knowledge (PCK) for teaching nature of science (NOS). Thirty preservice chemistry teachers enrolled in a Research in Science Education course participated in the study. Qualitative data sources included responses to an open-ended instrument, interviews, observations, and artifacts such as lesson plans and reflection papers. Through the in-depth analysis of explicit PCK and constant comparative method of analysis, we identified the influence of the intervention on participants' PCK for NOS. Analysis of data revealed four major themes related to the nature of preservice chemistry teachers' NOS teaching practices and their PCK for NOS: (1) prerequisite knowledge and beliefs are necessary to teach NOS, (2) there is a developmental progression of PCK for NOS from knowledge to application level, (3) teachers need some comfort in their NOS understanding to teach NOS, and (4) the higher integration of PCK components leads to successful NOS teaching practices. Implications for science teacher education and research are discussed.

**Keywords** Pedagogical content knowledge · Nature of science · Preservice teachers · Case study · In-depth analysis of explicit PCK · Constant comparative method

✉ Betül Demirdöğen
betuldemirdogen@gmail.com

1 Department of Science Education, Bulent Ecevit University, 67300, Kdz. Eregli, Zonguldak, Turkey

2 Department of Learning, Teaching, and Curriculum, University of Missouri Columbia, Columbia, MO 65211, USA

3 Department of Secondary Science and Mathematics Education, Middle East Technical University, 06800 Ankara, Turkey

4 Department of Secondary Science and Mathematics Education, Gazi University, 06500 Ankara, Turkey

## Introduction

Achieving scientific literacy for all has been emphasized in a host of reform documents in the USA (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC] 2011) as well as in Turkey, Britain, Netherlands, North America, Canada, Australia, and South Africa (Dillon 2009). In order for students to become scientifically literate, they should develop an understanding not only of *science concepts* but also an understanding of the enterprise of science and the *nature of scientific knowledge* (NOS). In terms of scientific literacy, understanding NOS is necessary to make sense of scientific information encountered in everyday life, understand socioscientific issues, and participate in the decision-making process (Driver et al. 1996).

Research identifies teachers as the most influential factor in classroom learning (Lumpe 2007; Miller 2001), so it is no surprise that students' failure to grasp NOS has focused researchers' attention on teachers. While research has been effective in identifying ways to address gaps in preservice and in-service teachers' understanding of NOS (Akerson et al. 2000; Lin and Chen 2002; McDonald 2010), research on teachers' classroom practice indicates that knowledge of NOS is a necessary, but not sufficient, condition for effective NOS instruction (Abd-El-Khalick et al. 1998; Akerson and Abd-El-Khalick 2003; Akerson and Volrich 2006; Lederman et al. 2001). As such, a recent focus of NOS researchers has been the knowledge teachers need in order to translate their views of NOS into forms accessible to learners, or their *pedagogical content knowledge for NOS* (PCK) (Hanuscin et al. 2011).

Developing PCK for NOS is more complex than merely acquiring a repertoire of NOS lessons (Abd-El-Khalick 2013; Hanuscin 2013; Schwartz and Lederman 2002). Rather, PCK is the integration of several different knowledge bases (Magnusson et al. 1999). These include knowledge of curriculum, learners, instruction, and assessment, as well as teachers' orientations toward science teaching. Research suggests that teachers need opportunities to examine subject matter (such as NOS) from a teaching perspective (van Driel et al. 1998) and be "…offered meaningful ways of defining, assessing and explicitly developing PCK" (Nilsson and Loughran 2012, p. 700).

Taking this into account, we developed instructional materials and activities to support the development of teachers' PCK for NOS in the context of a chemistry teacher education program. We acknowledge that preservice teachers have relatively undeveloped PCK (van Driel et al. 1998) and that preservice teachers' PCK may more appropriately be considered their "PCK readiness" (Davis 2003; Smithey 2003). Through case study, we examined the nature of preservice chemistry teachers' PCK for NOS in order to answer the overarching question, "How does instruction that uses PCK as an organizing framework influence the development of preservice teachers' PCK for NOS?" In seeking answers to this question, we also considered:

- To what extent does the nature of preservice teachers' individual component knowledge bases for PCK for NOS indicate their "PCK readiness"?
- How and to what degree are preservice teachers prepared to integrate the individual component knowledge bases of their PCK for NOS in their instructional planning?

## Literature Review

The design of our teacher education program and the study we conducted draws upon research literature related to both NOS and PCK.

## The Nature of Science

The "nature of science" (NOS) is a commonly used phrase by science educators to indicate ideas *about* science—issues of what science is and is not, how science and scientists work, the ontological and epistemological foundations of science, and how science and society impact one another (Clough 2006; McComas et al. 1998). However, the specific definition of NOS and what level of NOS understanding should be communicated to students has been a debate both among philosophers of science and science educators (e.g., Abd-El-Khalick 2013; Alters 1997; Irzık and Nola 2010; Smith et al. 1997).

As science educators, we cannot expect teachers or students to delve into the complexities of science from a philosophical stance that even scientists themselves do not need when doing science (Smith and Scharmann 1999). As Taber (2008) emphasizes, any account of NOS presented in school science is necessarily a simplification; the aim of introducing NOS is to provide students "a more complex understanding of science, not a total or even a very complex understanding" (Matthews 1998, p. 168). This more complex understanding should progress beyond what is currently emphasized in science textbooks (Abd-El-Khalick et al. 2008), taught by majority of science teachers (Abd-El-Khalick and BouJaoude 1997), and understood by students (Dogan and Abd-El-Khalick 2008).

In this study, we framed NOS using a set of characteristics of science common to reform documents and believed to be relevant and accessible to K-12 students (i.e., from kindergarten to 12th grade) (see Table 1) (Abd-El-Khalick et al. 1998; Lederman and Abd-El-Khalick 1998; McComas and Olson 1998; Osborne et al. 2003; Smith and Scharmann 1999). Although these aspects could be misinterpreted as merely declarative statements about science that students should memorize, our aim was to ensure that students can contextualize these aspects by analyzing contemporary and historic examples from science, and explain how these aspects relate to one another in terms of the practice of science (Ozgelen et al. 2013).

In our chemistry teacher education course, our instruction about NOS was *explicit-reflective*, in that we intentionally planned for, taught, and assessed ideas about NOS. Explicit does not mean to teach NOS directly or didactically. Rather, this approach requires identifying desired NOS learning outcomes. The reflective part of NOS instruction involves providing structured opportunities for learners to examine their experiences from an epistemological perspective, that is, thinking about the questions of development, validation, and the characteristics of scientific knowledge. The specific conceptual tools we utilized to enable students to think about and reflect on the activities in which they are engaged will be elaborated in detail in the methodology.

## Pedagogical Content Knowledge for Nature of Science

PCK is the specialized knowledge that differentiates a science teacher from a scientist (NRC 1996). Shulman first conceptualized PCK as the knowledge "which goes beyond knowledge of subject matter per se to the dimension of subject-matter knowledge for teaching" and he continues…

> …the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word, the ways of representing and formulating the subject that make it comprehensible to others. (1986, p. 9).

**Table 1** Aspects that constituted NOS understanding in this study

| NOS aspects | Explanation |
|---|---|
| Scientific knowledge is tentative | Although scientific knowledge is durable, it changes with the new data or reinterpretations of existing ones. This change might be a complete (e.g., phlogiston theory versus oxygen theory) or partial change (e.g., atom theories) |
| Science is based on observations and experiment | Scientists use observations and experiments when appropriate to test the validity of their claims. Not every scientific discipline enables scientists to conduct experiments such as astronomy or not all scientific knowledge is constructed as a result of experiments such as evolution theory |
| Scientific knowledge is based on inferences as well as observations | Scientific knowledge is the inferences derived from observations. Observations are descriptive statements about phenomena obtained by using senses (e.g., sight and hearing) or some technological devices (e.g., using scale to measure mass). However, inferences are the interpretations of these observations (e.g., Rutherford's atom model) |
| Scientific theories and laws have different roles in science | Scientific theories and laws have different meanings and roles in science. Scientific laws are the descriptive statements about the perceived relationships, regularities, patterns, and generalizations in nature (e.g., Boyle's law). On the other hand, scientific theories are the explanations for phenomena or laws (e.g., kinetic molecular theory) |
| Scientific knowledge is theory-laden and includes subjectivity | When scientists develop questions, design investigations, and make observations and inferences, their previous knowledge, experiences, expectations, and theories and laws that they believe unavoidably affect them |
| Creativity and imagination plays a major role in science | Logic by itself is not sufficient enough for science. Creativity and imagination are required during various phases of a scientific study such as constructing hypothesis and designing different ways for observations and experiments and finally interpretation of data |
| Social and cultural factors affect science | Politics, religion, philosophy, economy, and moral values are some of the factors which influence deciding what and how science is conducted, interpreted, and developed. In addition, scientific knowledge is produced, presented, and evaluated in social contexts including groups of scientists and scientific organizations |
| Science and technology is not the same thing | Science and technology are different from each other with regard to their purposes, methods, and products. The purpose of science is to explain natural world, while technology seeks solutions for human's problems and, hence, tries to make life easier. Scientists use scientific inquiry methods, while technicians use problem solving strategies such as technological design and construct. Scientific knowledge is the product of science and designs are products of technology. More importantly, technology is not the application for science |
| There is no universal and step by step scientific method | There are several common scientific processes such as forming hypothesis, observation, experimentation, interpretation, and hypothesis testing but these processes do not have to follow a specified order (e.g., Darwin proposed the theory of evolution right after his observations in Galapagos Islands without forming a priori hypothesis) |
| Serendipity plays a role in science | Chance (i.e., discovery as a result of unexpected situation) plays an important role in some scientific discoveries such as X-rays. Just chance is not enough for a scientist to discover new phenomena. Scientists paid attention to these things and interpreted it using their logic and, as a result, produced a scientific knowledge different than the one which they intended to investigate |

Since Shulman's initial proposition, much effort has been focused on the nature and development of PCK and subcomponents of PCK (Cochran et al. 1991, 1993; Grossman 1990; Magnusson et al. 1999; Shulman 1986, 1987; Tamir 1988) and teachers' PCK for different topics (De Jong et al. 2005; Friedrichsen et al. 2009; Henze et al. 2008); however, it is only recently that PCK has been used as a framework for researching teaching about the nature of science (Faikhamta 2013; Hanuscin 2013; Hanuscin et al. 2011).

Prior to any investigation of teachers' PCK for NOS, various PCK for NOS models were proposed by researchers. In 2000, Abd-El-Khalick and Lederman posited that PCK for NOS would include:

> … an adequate understanding of various aspects of NOS, knowledge of a wide range of related examples, activities, illustrations, explanations, demonstrations, and historical episodes. These components would enable the teacher to organize, represent, and present the topic for instruction in a manner that makes target aspects of NOS accessible to precollege students. Moreover, knowledge of alternative ways of representing aspects of NOS would enable the teacher to adapt those aspects to the diverse interests and abilities of learners (p. 692).

Since then, some researchers have developed their own NOS-specific PCK models (Abd-El-Khalick 2013; Jenny 2011; Kim et al. 2005; Schwartz and Lederman 2002) or utilized existing PCK models for investigating teachers' PCK for NOS (Faikhamta 2013; Hanuscin 2013; Hanuscin et al. 2011). Other studies have focused on teachers' PCK for NOS without an explicit PCK framework (e.g., Pongsanon et al. 2011). When examined more closely, however, these different conceptualizations of PCK for NOS have all shared elements of the PCK model proposed by Magnusson et al. (1999) (see Table 2).

Magnusson et al. (1999) viewed PCK as a transformation of subject matter knowledge, pedagogical knowledge, and knowledge of context. They conceptualized PCK as consisting of

**Table 2** PCK for NOS frameworks in literature with their components

| Components | PCK for NOS models | | | | |
|---|---|---|---|---|---|
| | Abd-El-Khalick and Lederman (2000) | Schwartz and Lederman (2002) | Kim et al. (2005) | Jenny (2011) | Faikhamta (2013), Hanuscin (2013), Hanuscin et al. (2011) |
| Nature of science | X | X | X | X | X |
| Subject matter knowledge | | X | X | X | X |
| Pedagogical knowledge | | X | X | X | X |
| Science teaching orientation | | X | X | X | X |
| Knowledge of instructional strategy | X | X | X | X | X |
| Knowledge of learner | X | | | X | X |
| Knowledge of curriculum | | | | | X |
| Knowledge of assessment | | | | X | X |
| History of science | | X | X | X | X |

five components: (a) orientations toward science teaching (teachers' knowledge and beliefs about the purposes and goals for teaching science at a particular grade level), (b) knowledge and beliefs about science curriculum (goals and objectives/curriculum and materials), (c) knowledge and beliefs about students' understanding of specific science topics (requirements for learning specific science concepts and areas of science that students find difficult including misconceptions), (d) knowledge and beliefs about assessment in science (knowledge of the dimensions of science learning that are important to assess and knowledge of the methods by which learning can be assessed), and (e) knowledge and beliefs about instructional strategies for teaching science (topic-specific activities and subject-specific strategies).

As aforementioned, several studies have applied the model of Magnusson et al. (1999) as a lens for research on PCK for NOS and have provided strong evidence for the utility of this model as a lens for research on NOS teaching (Faikhamta 2013; Hanuscin 2013; Hanuscin et al. 2011). Hanuscin (2013) examined critical incidents in the development of a prospective teacher's PCK for NOS and found that although the prospective teacher developed her knowledge of instructional strategies for teaching NOS in her methods' coursework, she did not develop the requisite knowledge of learners that would facilitate her successful NOS instruction. The researchers emphasized that teacher education and professional development efforts could be made more effective through a more comprehensive approach addressing all PCK subcomponents, rather than targeting only instructional strategies for NOS (e.g., explicit and reflective instruction) as has been common. They also highlighted a need for further research on interplay among PCK subcomponents in supported effective teaching about NOS.

Another recent study (Faikhamta 2013) investigated in-service science teachers' NOS understanding and orientation within a PCK-based NOS course. This course was framed using the PCK for NOS model that Hanuscin et al. (2011) adapted from the model of Magnusson et al. (1999). Throughout the course, teachers' NOS understanding was explicitly addressed, using reflective approaches embedded in both content-generic (e.g., mystery cube) and content-embedded activities (e.g., collision theories). Moreover, the course included instruction targeting each of the subcomponents of PCK (orientations, learners, instructional strategies, assessment, and curriculum). Analysis of the results showed that although in-service teachers had naive and partially informed ideas about several NOS aspects (e.g., laws and theories, and tentativeness) before the course, they improved these understandings. In the study, Faikhamta (2013) primarily considered orientations in relation to PCK. While the most prevalent orientations among teachers were initially project-based science, process, and guided inquiry, following the course, there were decreases in the frequency of those orientations and a shift was observed toward an inquiry orientation. The researcher did not consider other subcomponent knowledge bases of PCK nor the interaction of these.

Given that research has shown that the development of teachers' PCK may be uneven and that teachers may have more developed PCK for some components than others (Magnusson et al. 1999; Hanuscin et al. 2011), we focused our attention on each of the individual component knowledge bases of PCK. Nonetheless, we recognize that Magnusson et al. (1999) did not see their model just as a collection of the proposed components; rather, they emphasized that a teacher's level of PCK highly depends on the degree to which the components are integrated and coherent (see also Friedrichsen et al. 2009; Park and Oliver 2008). Therefore, in the present study, we were also concerned with the degree to which prospective teachers drew upon and made connections between these various components in their instructional planning.

Within the model of Magnusson et al. (1999), knowledge of curriculum refers to teachers' knowledge on mandated goals and objectives and specific curricular programs and materials related to the topic they teach. For example, this entails an awareness of specific curriculum materials and how these can be used to address NOS, as well as the various NOS objectives students are expected to achieve in particular grade levels. In Turkey, there is a national curriculum in which the same textbooks are used in all public schools. Within these textbooks, there is not an explicit and purposeful emphasis on NOS. Furthermore, we know of no supplemental curricular materials that are available in teachers' native language (the language in which they teach). This, combined with the fact that there were no specific NOS objectives in the secondary chemistry curriculum standards at the time our study was conducted, led us to omit teachers' knowledge of curriculum from our study. Rather, we utilized content-embedded and content-generic instructional strategies as a means to introduce supplementary curricular materials to teachers so that they might be able to teach NOS. While these have the potential to inform teachers' knowledge of curriculum, this was not a major focus of our work within the given context.

While past research has been successful in identifying ways to support teachers in developing an understanding of NOS, they have been less successful in terms of helping teachers develop PCK for NOS. Our study extends beyond previous research (Akerson and Abd-El-Khalick 2003; Akerson and Volrich 2006; Faikhamta 2013; Schwartz and Lederman 2002) by examining the development of prospective teachers' PCK for NOS at a critical juncture in their preparation (Abell 2008) and thorough examination of a comprehensive intervention framed through PCK (Hanuscin 2013).

## Research Design

### Method of Inquiry

The purpose of this study is to investigate the development and nature of preservice chemistry teachers' PCK for NOS using the model for PCK of Magnusson et al. (1999). Following recommendations by researchers in the recent literature, we focused on the degree of integration and coherence among the components of PCK (Abell 2008; Friedrichsen et al. 2009; Park and Oliver 2008). In this manner, we hoped to understand how instruction that uses PCK as an organizing framework influenced the development of preservice teachers' PCK for NOS and how that was expressed in their instructional plans. We chose to conduct a qualitative case study (Creswell 2003) to gain in-depth information about an innovative system (pedagogical instruction framed by PCK for NOS instruction) and little known phenomena (development PCK for NOS) (Marshall and Rossman 2011). We explored the development of PCK for NOS (an issue) in a bounded system (during PCK for NOS instruction period of an elective course) through multiple data collection sources including observations, interviews, audiovisual material, documents, and reports.

### Context: Research in Chemistry Education Course

The study took place within a teacher education program at a public university in Turkey that certifies undergraduates as chemistry teachers for grades 9–12. During their 5-year program, chemistry education majors take chemistry (e.g., general chemistry, analytical chemistry, organic chemistry, industrial chemistry), general pedagogical courses (e.g., introduction to education, instructional planning and evaluation), and subject-specific pedagogical courses (e.g., methods of science teaching, laboratory experiments in science education). In addition to these required courses, preservice chemistry teachers take elective courses on chemistry and chemistry education. A two-semester elective course, “Research in Chemistry Education” was the focus of our study. All the participants had completed chemistry, general pedagogical, and subject-specific pedagogical courses before this elective course. This two-semester elective course was offered to preservice chemistry teachers during their final year in the program. The course was scheduled as 3-h-long instructional sessions per week and all the sessions were done consecutively on a single day. The catalog description of the course did not specifically include a lab session. However, the course was designed as it includes lectures and labs depending on the topic covered each week. The classes were conducted in chemistry laboratory since students worked in groups and some activities required laboratory materials. The course formed the context for the second year of a 3-year government-funded project aiming to help both pre- and in-service teachers develop their understanding of NOS and ability to teach NOS (for more information about the project, see Köseoğlu et al. 2010). The content of this particular course was new for students, since they had not received explicit NOS instruction in their previous courses. The course included two instructional parts: the first was devoted to learning about NOS and the second was devoted to pedagogical instruction related to NOS. This latter part was framed by PCK for NOS.

### *Nature of Science Instruction*

Keeping in mind that understanding NOS is prerequisite to teaching NOS, participants first learned about NOS. In line with the literature, we used both content-generic and subject-specific activities to address NOS. Content-generic activities included The New Society (Cavallo 2008) and The Tube (Lederman and Abd-El-Khalick 1998) among others. We revised several content-embedded activities to address NOS, including Competing Theories: Lamarck and Darwin (National Academy of Sciences 1998), Why did the water rise? (Lawson 2002), and others. Additional activities were designed by the first author and the research project group to address agreed-upon common aspects of NOS and common myths about NOS (see Table 3). Using explicit-reflective NOS instruction (Abd-El-Khalick and Lederman 2000), we provided opportunities for participants to reflect on their experiences that they gained through engaging in the activity from the perspective of NOS. For example, in the activity “Science and Technology: In the Pursuit of Seharap—Designs are Competing,” participants engaged in the technological design process. Participants were presented the problem: “Design a vehicle which makes the transportation easier and safer for the farmers who have to climb high mountains to collect Seharap (i.e., a plant)”. The participants worked in groups of four or five to design a solution. After completion of design phase, the groups built models of their designs, tested their models, and revised it if needed. At the end of the activity, the instructor/s facilitated a whole class discussion on the nature of science and technology and relationship between them. Students were asked to consider the practices they engaged in and whether they considered these to be related to science or technology, and to consider the similarities and differences between science and technology in terms of their purpose, process, and product.

**Table 3** How did each explicit-reflective NOS activity address various NOS aspects focused in this study?

| Explicit-reflective NOS activities | NOS aspects | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Scientific knowledge is tentative | Science is based on observations and experiments | Scientific knowledge is based on inferences as well as observations | Scientific theories and laws have different roles in science | Scientific knowledge is theory-laden and includes subjectivity | Social and cultural factors affect science | Creativity and imagination plays a major role in science | Science and technology is not the same thing | There is no universal and step by step scientific method | Serendipity plays a role in science |
| 1. First step in NOS teaching: new society activity[a] | X | X | X | | X | X | X | | X | X |
| 2. Mysterious stones—lithology[b] | X | X | | | X | | X | | | |
| 3. Phases of the moon—lunar and solar eclipses[b] | | X | | | X | | | | | |
| 4. Competing theories—Lamarck and Darwin[a] | | X | X | | X | | | | X | |
| 5. Object coming from space—the role and importance of models in science[a] | X | X | X | | | | X | | | |
| 6. A case from HoS: phlogiston and foundation of modern chemistry[b] | X | X | X | | X | X | | | | X |
| 7. Discovery of DNA[b] | X | X | | | X | X | | | | |

**Table 3** (continued)

| Explicit-reflective NOS activities | NOS aspects | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Scientific knowledge is tentative | Science is based on observations and experiments | Scientific knowledge is based on inferences as well as observations | Scientific theories and laws have different roles in science | Scientific knowledge is theory-laden and includes subjectivity | Social and cultural factors affect science | Creativity and imagination plays a major role in science | Science and technology is not the same thing | There is no universal and step by step scientific method | Serendipity plays a role in science |
| 8. Thought experiments[b] | | X | | | | | X | | X | |
| 9. Superconductivity[b] | X | X | | X | | | | | | |
| 10. Science and technology: In the pursuit of Seharap—designs are competing[b] | | | | | | | X | X | | |

[a] Modified from the activities available in literature

[b] Developed by researchers studying in research project

### *Pedagogical Instruction Framed by PCK for NOS*

During the course, we utilized activities (summarized in Table 4) to enhance the various component knowledge bases that would inform the development of preservice teachers' PCK for NOS. These activities were planned by the first author and reviewed by faculty with expertise in teaching and learning about NOS. We relied on the model of Magnusson et al. (1999) for PCK to design instruction that would enhance prospective teachers' science teaching orientations (STO), knowledge of learners (KoL), knowledge of instructional strategies (KoIS), and knowledge of assessment (KoA), except knowledge of curriculum (KoC). The teaching module spanned 4 weeks (corresponding to 12 in-class hours). Each class session began with students answering a series of open-ended questions to elicit their ideas about the targeted component of PCK for NOS. Next, students engaged in argumentative

**Table 4** Activities designed to enhance different components of PCK for NOS

| Target PCK component | Example learning activities |
|---|---|
| *Orientations*<br>Debating on what knowledge is needed to decide on socioscientific issue facilitated students' reflection and revision of their purposes and goals for teaching science | 1. Watch a video of a mother who has to decide whether or not to get her baby vaccinated for swine flu (socioscientific decision making)<br>2. Debate conflicting ideas by two different teachers (one claims that it is enough to know biology and science concepts and the other advocates that further knowledge is needed to decide on socioscientific issues) |
| *Learner*<br>Arguing about various NOS conceptions enabled students to realize areas of science that students find difficult including misconceptions of NOS | 1. Explain participants about letters (including concept cartoons on myths of NOS) received from teachers who encountered problems in their class and needed participants' help<br>2. Argue about various NOS conceptions: Which one is accepted, which one is misconception. What is the source of misconceptions? And how can a teacher challenge a student to confront his/her misconceptions? |
| *Instructional strategies*<br>Analyzing two lesson plans and arguing on two science educators' views on lesson plans helped students to understand implicit and explicit-reflective approaches to NOS teaching and thus enhanced their knowledge of strategies and representations for teaching NOS | 1. Case study scenario: Assist a chemistry teacher who needs help in designing a chemistry lesson in a way to teach both chemistry and NOS concepts<br>2. Distribute two lesson plans prepared on the same chemistry concepts: one where teaching NOS is implicit and the other where teaching NOS is explicit-reflective<br>3. Analyze lesson plans in terms of alignment between their intended objectives, the teaching method, and the appropriateness of teaching method achieving (or satisfying) the objectives<br>4. Argue about two science educators' views on lesson planning: one supports an implicit approach and the other one supports an explicit-reflective approach |
| *Assessment*<br>Assisting a teacher with aligning his/her assessment task with the lesson objectives including chemistry and NOS helped students to consider NOS as a dimension of science learning and the methods by NOS can be assessed | 1. Give both chemistry and NOS objectives from lesson plans analyzed in the previous class<br>2. Case study scenario: Assist a chemistry teacher with aligning his/her assessment task with the lesson objectives<br>3. Ask preservice teachers to give specific examples of an assessment task |

discussions within small groups and presented their ideas to the class. The instructor facilitated the discussions and wrapped up the session with a presentation related to the session's focus. Students ended the session by writing a reflection on their learning. For example, in one session about STO, the purpose of this class was to reveal participants' orientations toward teaching chemistry and encourage them to reflect on the value of NOS teaching. Students were first asked to consider the goals of science and chemistry education and the kinds of instruction necessary to achieve those goals. Preservice chemistry teachers then watched a video of a mother who is trying to decide whether or not she should get her baby vaccinated for swine flu (socioscientific decision making). Then, the participants were presented with two different science teachers' arguments about the types of scientific knowledge the mother would need to make an informed decision. One argument claims that it is enough to know biology and related science concepts, while the other advocates that, in addition to science concepts, further knowledge (i.e., NOS) is needed to make an informed decision about getting the baby vaccinated. The participants were asked to select one of the arguments by providing evidence and warrants. During this process, preservice chemistry teachers worked in groups of five or six and then presented their ideas to the class. During these presentations, the instructor facilitated the discussions and then closed the session with a presentation about scientific literacy and the importance of NOS. Following this, the participants wrote a reflection paper about their ideas. We use "PCK for NOS instruction" hereafter, but do not intend this to mean we explicitly introduced the PCK construct to students. Rather, we used framing questions aligned with this construct for each session (e.g., "Why are you teaching science?" for science teaching orientations and "What kind of instructional strategies do you use for teaching NOS?" for knowledge of instructional strategies).

## Participants

Participants included 30 preservice chemistry teachers (8 males and 22 females). All started an undergraduate teacher education program in 2005 and their ages ranged between 22 and 24 with an average of 23. All were in their senior year and in a position to graduate at the end of the year in which the study was conducted. Each had similar background in terms of coursework, including chemistry courses (e.g., organic chemistry), pedagogical courses (e.g., classroom management), and subject-specific pedagogical courses (e.g., science teaching method). The participants were typical in the sense that they took similar courses during their teacher education program compared to other chemistry education majors in other universities in Turkey.

## Data Collection Sources

This study relied on qualitative data sources to gain in-depth information about the phenomenon being investigated, as summarized in Fig. 1. Data sources included responses given to open-ended instruments, interviews, observations, and documents such as lesson plans and reflection papers. We used the Views on Nature of Science Questionnaire Form C (VNOS-C, Lederman et al. 2002) in conjunction with follow-up interviews before and after the NOS instruction. To investigate the development of preservice chemistry teachers' PCK for NOS, we utilized interviews, reflection papers, responses to open-ended instruments, observational

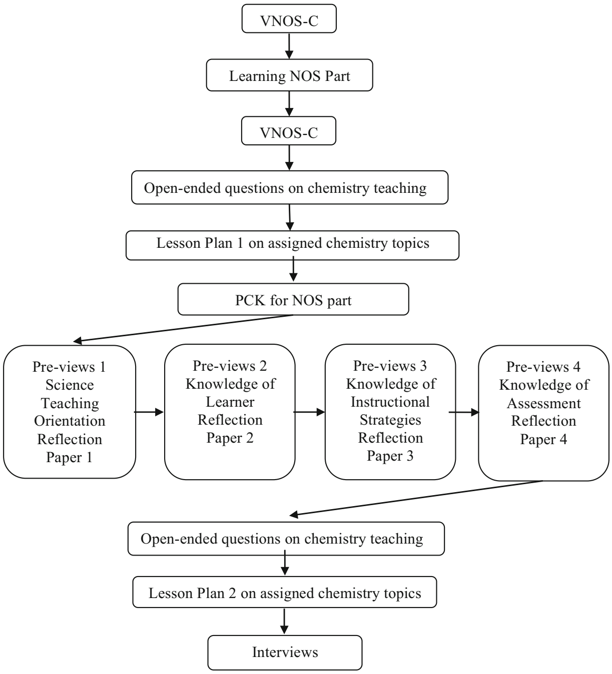



**Fig. 1** Flowchart of data collection within the various course activities

records including videos, and lesson plans. Figure 1 shows how data collection occurred within the various course activities.

### *Views on Nature of Science Questionnaire Form C*

The VNOS-C and associated follow-up interviews formed the main data source in identifying how preservice chemistry teachers' NOS views changed. Although there were 10 activities in NOS instruction, some activities lasted more than three course hours that correspond to at least 2 weeks. Therefore, the implementation of 10 activities spanned one and one-half semesters. The VNOS-C was administered two times: before NOS instruction (at the beginning of the first semester) and finally after NOS instruction (in the mid of the second semester). Therefore, in this study, the change in preservice chemistry teachers' NOS understanding will be elaborated in terms of how they were used to understand NOS before NOS instruction and what kind of NOS views they had after NOS instruction.

### *Open-Ended Questions*

We used two types of open-ended questions. The first type was used to understand whether learning the NOS part influenced participants' views on chemistry teaching and to make a comparison between their views on chemistry teaching before and after PCK for NOS instruction. For example: *What is the goal of science and especially chemistry education*? *What kind of instruction do you design to achieve the goals you mentioned in previous* *questions*? *What are the difficulties that you may encounter when you are teaching what you want to teach*? The second type of open-ended question is related to the focus component of PCK (Table 5) and served as a comparison point to responses obtained at the end of the class through reflection papers.

### *Reflection Papers*

To clarify each session's effect on preservice chemistry teachers' knowledge of the related PCK component, students were asked to write reflection papers following each PCK for NOS session. The questions in reflection papers were as follows: *What is the message of this lesson*? *What did you learn about chemistry/science education*? *How did this lesson change your perspective on chemistry/science education*? *How do the things you learned in this lesson affect your ideas about chemistry/science teaching*?

### *Lesson Plans*

Two lesson plans were collected: the first after students learned about NOS but before instruction targeting their PCK and the second at the end of the course (Fig. 1). The first lesson plan was helpful for providing supporting or counter evidence for the view that even if teachers have informed understanding of NOS consistent with reforms, they generally do not explicitly teach NOS (Schwartz and Lederman 2002). Several possible chemistry topics (e.g., particulate nature of matter, atom, solutions, and mole) were assigned to the participants. The participants were free to select the concepts on which they wanted to focus within these topics and they were not explicitly instructed to integrate NOS into their instruction. A lesson plan format including several parts such as general and specific objectives, teaching strategy, detailed explanation of their instruction, and assessment was given to preservice chemistry teachers. Lesson 2 was collected after PCK for NOS instruction, in which preservice chemistry teachers were asked to revise their earlier lesson plan 1. Lesson plan 2 was used to determine whether and how our instruction assisted preservice chemistry teachers in translating their NOS understanding into their lesson plans.

We intentionally omitted explicit instructions to integrate NOS in order to assess whether students were likely to do this on their own (versus simply doing so to fulfill the assignment).

**Table 5** Prequestions asked before each PCK for NOS instruction class

| Class | Questions |
|---|---|
| STO | • As a teacher candidate, in your view, what is the goal of science education and specifically chemistry education?<br>• As a teacher, in your view, what kinds of knowledge, skills, etc. a student should have as a result of science and especially chemistry teaching? |
| KoL | • What might your students already know about NOS?<br>• Why do you think that they might know that?<br>• Where do you think they might have learned these? |
| KoIS | • What kind of instructional strategies do you use for teaching NOS and chemistry concepts at the same course hour? |
| KoA | • Help a teacher who has difficulty in assessing his objectives including both chemistry and NOS and gave suggestions for assessment. |

Given flexibility in choice of topic/concept, we did not expect that all participants would integrate the same NOS aspect or aspects. Rather, we focused on (1) whether they identified a specific NOS learning outcome, (2) whether that aspect was appropriate to the choice of topic/concept, and (3) how they proposed to teach and/or assess that NOS learning outcome. For instance, two participants who opted to teach factors affecting the rate of reactions both used the 5E learning cycle method. One of them integrated the empirical basis for scientific claims and the use of creativity in science, while the other focused on the role of creativity and the myth of scientific method. Similarly, two participants who integrated the inferential NOS prepared their lesson plans on different chemistry topics (i.e., particulate nature of matter versus electrochemistry).

*Interviews*

Two types of semistructured interviews were conducted in this study. The first one was conducted with nine participants in order to understand the meanings they ascribed to NOS aspects. During those interviews, respondents were provided their questionnaires and asked to explain and justify their responses. The second type of interview was conducted after PCK for NOS instruction with nine participants in order to gain an in-depth understanding of their PCK development and how PCK for NOS instruction contributed to this development. Several examples for the interview questions are as follows:

- Was there any change in your views about what you expect students to learn about chemistry before NOS instruction, after NOS instruction, and after PCK for NOS instruction? If yes, how?
- Do you think that your students should learn NOS? Was there any change in your views about this before NOS instruction, after NOS instruction, and after PCK for NOS instruction? If yes, how?
- What kind of instructional strategies would you use or did you use to teach NOS? How did learning NOS part and PCK for NOS part contribute to your knowledge of instructional strategies? Which instructional strategies are more effective than others? Please, explain why.

*Participant Observation*

Eleven researchers (of whom two are the authors of this paper) were part of the project that funded the Research in Chemistry Education course, and each had a share in instructional responsibilities for the project. Thus, while some team members were engaged in teaching, the other team members served as participant observers to capture data. As a secondary data source, information gathered as the participant observers facilitated small group discussions helped enhance the credibility of our interpretations of students' reflection papers. In each class, the research group of two or three was the leader in conducting all the course activities. However, the other researchers in the project were also responsible during the guidance provided to small group discussions. All class sessions were videotaped as well, to enable us to document our PCK for NOS instruction (Flick 1996).

## Data Analysis

Two main analyses were conducted to determine how the preservice chemistry teachers' NOS understanding and their PCK for NOS changed throughout PCK for NOS instruction.

### *Analysis of NOS Views*

In order to identify participants' NOS views before and after NOS instruction, data obtained from VNOS-C and follow-up interviews were analyzed deductively. An already existing categorization proposed by Khishfe and Abd-El-Khalick (2002) was used for identifying participants' NOS views. Khishfe and Abd-El-Khalick (2002) advocated that there is a continual change in students' understanding about NOS. Considering this continuum, preservice chemistry teachers' NOS understandings were categorized as naive, transitional, and informed. Each NOS aspect addressed in this study was evidenced itself in more than one data source (interview and VNOS-C) and, moreover, in more than one item in VNOS-C. A participant's view on a particular aspect was categorized as informed if s/he had provided evidence of meaningful understanding related to that aspect in all contexts. If a participant had not exhibited any meaningful understanding with respect to a particular aspect in all contexts, his/her view of the related aspect was categorized as naive. If a participant had demonstrated meaningful understanding of a particular aspect in some contexts but not the others, his/her view in that aspect was categorized as transitional.

### *Analysis of Participants' PCK for NOS*

Analysis of participants' PCK for NOS focused on lesson plans 1 and 2, reflection papers, responses to open-ended questions, and interviews. This analysis involved both deductive and inductive analysis (Patton 2002). In the deductive phase, we conducted in-depth analysis of explicit PCK (Park and Chen 2012; Park and Oliver 2008), and in the inductive phase, we used the constant comparative method (Glaser and Strauss 1967).

**In-Depth Analysis of Explicit PCK** In order to determine the PCK for NOS components developed by participants and the degree of integration of these components, a modified version of in-depth analysis of explicit PCK (Park and Chen 2012; Park and Oliver 2008) was employed during the deductive phase of qualitative analysis. This method mainly relies on construction of a PCK profile for each participant as defined by the model of Magnusson et al. (1999). Although preservice chemistry teachers were asked to prepare lesson plan 1 right after the NOS instruction, they did not integrate any NOS aspects explicitly in their lesson plans. When asked whether they attempted to teach NOS in the lesson, only two participants claimed to teach NOS by engaging students in an inquiry-based learning setting (i.e., and implicit approach). Therefore, while the PCK profiles were created, mainly lesson plan 2, reflection papers written at the end of each PCK for NOS class, responses to open-ended questions given at the beginning of each PCK for NOS class and after PCK for NOS instruction, and interviews conducted with nine participants were used as suggested in literature to assess and capture the complexity of PCK (Baxter and Lederman 1999). The PCK profile consisted of several components including (see Appendix) (a) chemistry topic on which the lesson plan was prepared, (b) objectives including science process skills and NOS aimed to be achieved, (c) synopsis of the lesson plan prepared after PCK for NOS instruction, (d) evidence for the components of PCK for NOS and connections among them, (e) a description of where the PCK for NOS components was evident throughout data collection, and (f) postintervention PCK for NOS map representing which components and connections or consistencies are present. The final PCK for NOS map included only four components of the model of Magnusson et al. (1999), namely, STO, KoL, KoIS, and KoA since KoC was not a focus in PCK for NOS instruction. Different types of lines were used to show connections and consistencies among the PCK for NOS components which were evident in different data sources:

- Bold lines for the connections and consistencies that exist in lesson plans
- Solid lines for the connections and consistencies that exist in reflection papers
- Dashed lines for the connections and consistencies that does not exist in any of the data sources It was obvious that the strength of one connection or consistency between two components might be different from another and it was. Although we assumed the same strength for each connection or consistency for convenience (Park and Chen 2012) when drawing the PCK for NOS map for each participant, we considered the differences in power of consistencies and connections when presenting the results. In order to decide whether a connection or consistency was evident in any of the data source, a coding scheme was formed (see Table 6). This coding scheme described the instances of PCK components and integration of components in preservice chemistry teachers' PCK. During the formation of the coding scheme, we relied on the data and literature using in-depth analysis of explicit PCK (Park and Chen 2012; Park and Oliver 2008). Based on the data and the literature, we defined every possible instance which can be counted as an evidence for any PCK component and consistencies or connections among them. Formation of the coding scheme was accomplished by a researcher who is an expert on both PCK and PCK for NOS by discussing and negotiating any incongruities. For deciding whether the integration between any two PCK components addressed in this study was an indication of consistency or connection, we utilized the PCK literature during the formation of our coding scheme. With the recognition of the way in which STO shapes KoL, KoIS, and KoA (Magnusson et al. 1999), any integration between STO-KoL, STO-KoIS, and STO-KoA was coded as *consistency*. On the other hand, any integration which was observed for any two components of KoL, KoIS, and KoA was coded as *connection* since each has the capacity to inform other (Abell 2008) (e.g., KoL might inform KoIS and KoA might inform KoL).

**The Constant Comparative Method** After completion of profiles for each participant and accompanying postintervention PCK for NOS maps, we focused on the identification of patterns or regularities among the maps, resulting in two-dimensional categorizations for participants' PCK. One dimension shows the degree to which the components are integrated. Since there were four components focused in this study (STO, KoL, KoIS, and KoA), the maximum number of connections among the components of PCK is six and the degree of integration ranged between highly integrated (number of connections/consistencies is 5 and 6), somewhat integrated (number of connections/consistencies is 3 and 4), and nonintegrated (number of connections/consistencies is 1 and 2). The other dimension represents the degree to which preservice teachers can translate their PCK to their practice, and it ranged between knowledge (map includes one bold line

**Table 6** Coding scheme describing instances of PCK components and integration among them

| PCK components | Instance | Consistency or connection | Direction |
|---|---|---|---|
| STO-KoL | • If preservice teacher is aware that students have misconceptions in NOS<br>• If preservice teacher is teaching for one of the myths about NOS (e.g., hierarchical relationship between theory and law) | Consistent | STO influenced KoL |
| STO-KoIS | • If preservice teacher uses implicit or explicit approach to teach NOS | Consistent | STO influenced KoIS |
| STO-KoA | • If preservice teacher assesses NOS | Consistent | STO influenced KoA |
| KoA-KoL | • If preservice teacher makes an assessment to reveal students' misconceptions about NOS at the beginning | Connection | KoA informed KoL |
| | • If preservice teacher assesses students' misconceptions about NOS s/he communicated in his/her lesson plan at the end | Connection | KoL informed KoA |
| KoA-KoIS | • If preservice teacher makes an assessment to reveal students' misconceptions about NOS at the beginning and then designs instruction based on assessment result | Connection | KoA informed KoIS |
| KoA-KoIS | • If preservice teacher makes an assessment compatible with the instructional strategy (e.g., relabeling observations and inferences they made at the beginning of the lesson, preparing a poster on their investigation they made throughout the lesson, preparing a periodic table using each group's data) | Connection | KoIS informed KoA |
| KoL-KoIS | • If preservice teacher designs an instructional strategy to eliminate students' misconception (paying attention to use of words, after communicating observation and inference using gestalt pictures, after communicating several nature of science aspects asking questions to assess students' understanding and then talking about nature of science whether there is a misconception) | Connection | KoL informed KoIS |
| | • If a preservice teacher teaches to eliminate a misconception (e.g., to eliminate the myth that experiments are not the principal routes to scientific knowledge, teacher uses some cases from a science magazine where scientists only use observations or step by step scientific method and makes the students to get involved in scientific process) | Connection | KoL informed KoIS |

and the rest is solid), knowledge-application (map includes a mixture of bold and solid lines), and application level (map only includes bold lines). We developed categories based on the maps using an interactive process of constant comparison (Glaser and Strauss 1967).

### Credibility Issues of the Study

In this study, triangulation and prolonged engagement were used to ensure credibility. We used multiple data sources to triangulate our findings in the current study as well as analyst/investigator triangulation using multiple observers, interviewers, and analysts. Throughout all data collection process, at least three researchers who are familiar with NOS and PCK were present during course instruction. During the analysis stage, two analysts, among those researchers, independently coded the data for NOS and PCK for NOS after forming a rubric for NOS and a coding scheme for PCK for NOS. Moreover, four researchers who were studying PCK individually compared participants' PCK for NOS maps and then reached a consensus on categories inductively derived from the data. The rubric for NOS directly came from NOS literature (Khishfe and Abd-El-Khalick 2002), and the coding scheme used for creating PCK for NOS profiles including participants' maps was formed by two authors, one of whom is an expert on both PCK and PCK for NOS, by discussing and negotiating any incongruities. After formation of the rubric and coding scheme, two independent researchers coded the data for NOS and PCK for NOS. The incongruities between researchers were resolved by negotiation and discussion. Interrater reliabilities were calculated at 95 % for NOS and 90 % for PCK for NOS. The inconsistencies between coders were resolved by negotiating and discussing.

Prolonged engagement is achieved by being present in the research site for an extended period of time. Two of the researchers spent a whole year, including two semesters, within this research setting and with these participants. Most of the time, two authors were among the leading instructor of the class and had a chance to observe and talk with participants in and out of the class settings.

We note that data were collected and analyzed in the participants' native language (Turkish), and then findings were translated into English. The first and third authors, who are competent in English speaking, writing, and reading translated the findings into English. Those findings were back-translated to Turkish by an outside science educator. Inconsistencies between translators were resolved to ensure accurate translation. Finally, all English translations were reviewed for clarity by a native English speaker.

### Ethical Issues of the Study

All study activities were conducted in alignment with the Institutional Review Board (IRB). All participants voluntarily participated in the study through written consent form. During class sessions, students were aware of the role of participant observers (who also had teaching roles). As such, an external gatekeeper (Department Chair) served as a point of contact for participants to voice any concerns. Through this, issues regarding ethics in research, such as protection of the participants from harm, and confidentiality were assured (Fraenkel and Wallen 2006).

## Findings

Developing teachers' PCK for NOS is a challenge for science teacher educators. Therefore, we developed a specialized course to enhance both preservice chemistry teachers' NOS understanding and their PCK for NOS. To investigate how preservice teachers' NOS teaching practices developed throughout the course, we collected multiple data sources including lesson plans, responses to open-ended questions, reflection papers, and interviews. Analysis of data revealed four major themes related to the nature of preservice chemistry teachers' NOS teaching practices and their PCK for NOS. The findings will be presented according to those themes, which focus on (1) prerequisite knowledge and beliefs necessary to teach NOS, (2) developmental progressions in PCK for NOS, (3) relationship between subject matter knowledge and PCK for NOS, and (4) interaction and integration of components of PCK for NOS.

## Prerequisite Knowledge and Beliefs Necessary to Teach NOS

Analysis of data revealed that both adequate NOS understanding and beliefs in the importance of learning NOS are necessary for ensuring that teachers attempt to teach NOS, either implicit or explicit. Even after learning NOS, and indicating a reasonable progress in NOS understanding, only one preservice teacher integrated NOS into her planning; however, she used an implicit approach without stating her NOS-related objectives explicitly. In her postinterview, she stated that she assumed students could learn NOS through experiencing the science itself. No other preservice teachers indicated intent to teach NOS in their first lesson plan. This supports earlier research that showed understanding of NOS is necessary but not sufficient to teach NOS and emphasized the importance of teachers' *intentions* to teach NOS (Schwartz and Lederman 2002); however, our study provides empirical evidence that an approach framed by PCK is productive in helping shift teachers' orientations in ways that support their intention to teach NOS.

Learning about NOS content (the first part of the course) had little impact on pre-service teachers' beliefs about the goals and purposes of teaching chemistry, as Grey[1], **one of the pre-service chemistry teachers participated to the study**, explained in her interview:

> In the first part where we learned about nature of science, I did not think that nature of science is something that I should teach to my students. In the second part where we learned how to teach nature of science, I realized the importance of nature of science for scientific literacy and decided to integrate into my teaching. Moreover, while I was learning about nature of science, [I realized that] I used to think that nature of science can be learned implicitly…. (Grey, post PCK for NOS interview)

On the other hand, we noted substantial changes in preservice teachers' orientations after our PCK for NOS instruction; 93 % (28 out of 30) of preservice teachers believed in the importance of learning NOS for their students during their chemistry teaching. This transition was evident both in their reflections on their teaching and learning and in their lesson plans. The majority of preservice teachers designed a lesson to teach at least one aspect of NOS. For instance, Margaret designed an inquiry-based lesson for teaching metallic activity. More importantly, she used explicit-reflective and content-embedded approach to teach three major ideas about NOS: (a) nature and role of experiments in science, (b) the role of creativity and imagination in science, and (c) the subjectivity in science. Margaret explicated how she changed her orientation as follows:

> Before the [first session of pedagogical instruction about NOS], I was thinking that I should just teach chemistry to my students. Then, I realized the importance of communicating nature of science to my students… (Reflection paper 3)

[1] All names of the participants are pseudonyms.

## Developmental Progression of PCK

The analysis of 30 preservice chemistry teachers' postintervention PCK for NOS maps showed that all participants developed PCK for NOS (at least some components) and integrated this knowledge to some extent. The differences in the levels of integration suggest a developmental progression in participants' PCK from knowledge about how to teach NOS (knowledge level) to translation of that knowledge in their lesson design (application level). This seemed to increase as components of participants' PCK became more integrated. As shown in Table 7, those with more highly integrated PCK were more likely to include NOS teaching in their lessons.

In the sections that follow, we highlight the cases of three participants, Nancy, Irving, and Howard, to illustrate the variation in their PCK integration and degree of translation (Fig. 2).

For example, Nancy had *highly integrated PCK* and her lesson demonstrated *application* of this in her lesson plan (see Fig. 2a). She was oriented to teach NOS and included NOS objectives in her lesson plan (i.e., tentativeness, subjectivity, and creativity and imagination in science) as well as chemistry-related ones. Nancy planned her lesson considering students' difficulties and misconceptions about NOS. She administered 10 questions in true-false format as a preassessment. In other words, she successfully aligned her instructional strategy, learner, and assessment with her teaching orientation (i.e., NOS) in her lesson plan. Three of the questions were directly related to NOS which are as follows:

- Definitions about the phases of matter is absolute.
- Scientists produce unchangeable knowledge since they do numerous tests.
- Scientists claim that previous knowledge in the discipline is wrong since they do not like each other. (Nancy, lesson plan 2)

Nancy stated that "The purpose of administering this test is to elicit students' misconceptions and design instruction considering students' misconceptions". That is her knowledge of learner informed her assessment which in turn linked to her instructional strategy. She used 5E learning cycle to teach NOS aspects in an explicit-reflective and content-embedded way. Moreover, Nancy assessed students' understanding of NOS at the beginning, throughout,

**Table 7** Number and percentage of participants in each PCK category

| Degree of integration of PCK components[a] | Degree of translation into lesson plan[b] | | | Total |
|---|---|---|---|---|
| | Knowledge | Knowledge-application | Application | |
| Highly integrated | 2 (6 %) | 2 (7 %) | 10 (33 %) | 14 (47 %) |
| Somewhat integrated | 4 (13 %) | 3 (10 %) | 6 (20 %) | 13 (43 %) |
| Nonintegrated | 0 | 0 | 3 (10 %) | 3 (10 %) |
| Total | 6 (20 %) | 5 (17 %) | 19 (63 %) | 30 (100 %) |

[a] Highly integrated groups' maps include five and six connections/consistencies, somewhat-integrated groups' maps include three and four connections/consistencies, and nonintegrated groups' maps include one and two number of connections/consistencies

[b] Knowledge-level participants' maps include one bold line and the rest is solid, knowledge-application-level participants' maps include a mixture of bold and solid lines, and application-level participants' maps only include bold lines

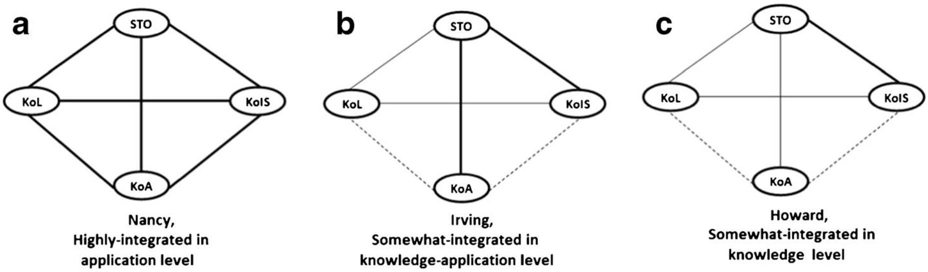



**Fig. 2** **a**–**c** Three preservice teachers' PCK for NOS maps from different levels of translation

and/or at the end of the lesson. While there can certainly be improvements made to Nancy's specific assessments, what is critical here is the degree of alignment between the component knowledge bases of her PCK evident in her approach.

In contrast to Nancy, Irving (see Fig. 2b) had *somewhat-integrated PCK*. His lesson indicated application of some PCK components in the plan whereas other components stayed at the knowledge level. In other words, his PCK stayed at the *knowledge-application* level. Considering that an increase in the degree of translation level is associated with an increase in the degree of integration of PCK components, Irving had somewhat-integrated PCK in knowledge-application category as opposed to Nancy whose PCK is highly integrated in application category. Irving was able to translate orientation, instructional strategy, and assessment components of his PCK into his planning, but not his knowledge of learners. He focused on empirical-based and subjective NOS elements using an explicit-reflective and content-embedded approach in his planning. Irving designed a 5E learning cycle lesson on the topic of saturated, unsaturated, and supersaturated solutions. He stated that he would informally assess students' NOS understanding about targeted NOS aspects. However, he did not provide any evidence for his knowledge of learner related to the NOS aspects (e.g., scientists are particularly objective) in his lesson plan although he explained what he could do for not causing a misconception as follows:

> I realized that students may have various misconceptions about the nature of science. Teachers and instruction are two of the sources of these misconceptions. I will be careful about the language I use during my teaching. Since, my language may lead students to have some misconceptions such as hierarchical relationship between theory and law. (Irving, Reflection paper 2)

Lastly, Howard (see Fig. 2c) had *somewhat-integrated PCK* and his lesson did not indicate application of this. Instead, the majority of Howard's components and connections were at the *knowledge* level. Only his orientation and instructional strategy components were evident in his lesson plan. On the other hand, his knowledge of learner and assessment components stayed at the awareness level. Howard explicitly and reflectively integrated tentativeness of science in his lesson plan on acid–base theories. He used a history of science approach to teach acid–base concepts and NOS aspects. However, Howard did not consider students' difficulties and misconceptions about tentativeness. Nor did he assess what students learned about scientific knowledge throughout his lesson plan. Nonetheless, he emphasized the importance of considering misconceptions and mentioned about strategies to assess NOS in his postinterview as follows:

> When I saw the concept cartoons [second session of pedagogical instruction about NOS], I realized that there are some students who have various kinds of misconceptions about the nature of science… I thought that I should elicit students' misconceptions first. If we ignore the existence of misconceptions, students will not learn targeted nature of science aspects and will continue to keep their misconceptions…I can use concept maps, KWL charts, true-false items, or cases to assess students' understanding about nature of science.

## Relationship Between Subject Matter Knowledge and PCK

While previous studies have examined the relationship between content knowledge of NOS and teachers' instructional practices, this study provides a more holistic picture of teachers' practices through the lens of PCK. In order to reveal the relationship between preservice chemistry teachers' NOS understanding and their PCK for NOS, how each participant changed his/her NOS views is considered first (see Table 8).

Analysis of VNOS-C administered before NOS instruction indicated that preservice chemistry teachers had various misconceptions about NOS (e.g., hypotheses become theories that turn into laws, scientists are particularly objective). When all NOS aspects addressed in the NOS instruction were considered, the percentage of naive (33 %) and transitional (28 %) views was 61 %, whereas the percentage of informed views was 26 % (13 % of the views were missing). While the vast majority of the participants (80 %) had naive views about theory-law aspect of NOS, interestingly, no participant had naive views about creative and imaginative NOS aspect. However, in terms of the creative NOS, 43 % of the participants had transitional views. Analysis of data from the VNOS-C administered after the NOS instruction revealed that participants' NOS views changed in the desired way. When all NOS aspects addressed in the NOS instruction were considered, the average percentage of transitional (21 %) and naive (5 %) views decreased substantially, whereas the percentage of informed views rose to 73 %. In spite of the increase in informed NOS views, preservice chemistry teachers still had difficulty in understanding empirical-based (7 %) and social- and cultural-embedded NOS (7 %) as well as the difference between theory and law (13 %) and observation and inference (10 %).

Various comparisons made among the participants from various groups (i.e., participants in three categories of degree of integration and participants in three categories of degree of translation) to clarify how NOS understanding contributes to the nature of PCK for NOS revealed that there was no clear pattern or relationship between those two (e.g., the more the number of informed views a participant has about NOS, the more integrated PCK for NOS s/he has).

For a closer look at the relationship between NOS understanding and NOS teaching practices, we attended to participants' choice of which aspects of NOS to emphasize in their lessons in relation to their understanding of NOS, whereas other studies have examined teacher's understanding of NOS in relation to whether or not they explicitly taught NOS. Our data suggest that some comfort in preservice chemistry teachers' own understanding of NOS is prerequisite to teaching NOS. The vast majority of preservice chemistry teachers (70 %) chose to include NOS aspects about which they had informed views. Others who integrated NOS aspects that were not addressed in VNOS-C (17 %) or who included aspects

**Table 8** The change in participants' NOS views and their PCK for NOS

| Participant | NOS aspects | | | | | | | | | | | | | | PCK for NOS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tentativeness | | Empirical-based | | Observation and inference | | Theory and law | | Theory-laden | | Sociocultural-embedded | | Creativity and imagination | | |
| | Before | After | Before | After | Before | After | Before | After | Before | After | Before | After | Before | After | |
| Aaron | I | I | T | *I* | I | I | N | I | T | T | I | *I* | T | *I* | HI-K |
| Aida | T | I | T | T | N | I | N | T | N | I | N | I | T | I | SI-A |
| Albert | M | *I* | M | *I* | M | T | M | N | M | T | M | I | M | T | SI-A |
| Becca | T | I | I | *I* | I | I | N | N | N | I | N | I | I | I | HI-KA |
| Beatrix | M | I | M | I | M | *T* | M | I | M | T | M | I | M | I | HI-A |
| Debbie | N | I | T | I | N | N | N | *I* | I | T | N | I | I | I | HI-A |
| Emily | T | I | I | I | I | I | N | T | N | I | N | I | T | *I* | SI-A |
| Eric | I | I | I | T | T | *T* | N | I | T | I | I | I | I | I | SI-K |
| Fletcher | M | *I* | M | I | M | T | M | N | M | *I* | M | T | M | I | NI-A |
| Florrie | T | I | I | I | I | *T* | N | I | T | I | N | I | I | I | SI-A |
| Gracie | T | I | T | *I* | N | T | N | I | T | I | N | I | I | I | HI-A |
| Grey | I | I | N | I | I | I | N | *I* | T | I | N | I | T | I | HI-A |
| Ginger | I | I | T | I | N | T | N | I | N | I | N | I | T | I | HI-K |
| Howard | N | *I* | I | I | T | T | N | T | I | *I* | N | I | I | I | SI-K |
| Hailey | T | T | N | N | I | N | N | I | I | I | I | T | I | I | HI-A |
| Hope | T | I | I | *I* | N | I | N | I | I | I | I | T | I | I | SI-A |
| Howie | T | I | T | I | I | I | N | N | N | I | I | I | T | *I* | NI-A |
| Irving | I | I | I | *I* | I | I | N | I | N | T | I | T | I | I | SI-KA |
| Katy | I | I | N | N | I | *I* | I | I | I | I | I | I | T | *I* | SI-K |
| Madeline | N | I | T | T | N | *I* | N | I | I | *I* | N | I | I | *I* | HI-A |
| Margaret | N | I | N | I | I | I | N | I | N | *I* | I | I | T | *I* | SI-KA |
| Marcie | I | *I* | N | I | T | I | N | *I* | N | *I* | N | I | T | *I* | HI-A |

**Table 8** (continued)

| Participant | NOS aspects | | | | | | | | | | | | | | PCK for NOS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tentativeness | | Empirical-based | | Observation and inference | | Theory and law | | Theory-laden | | Sociocultural-embedded | | Creativity and imagination | | |
| | Before | After | Before | After | Before | After | Before | After | Before | After | Before | After | Before | After | |
| Nancy | I | *I* | I | I | I | I | N | I | I | *I* | N | T | I | I | HI-A |
| Norah | T | I | T | I | T | I | N | I | I | I | N | I | T | I | HI-A |
| Oakley | I | I | T | T | T | N | N | T | I | I | I | T | I | I | SI-K |
| Olivia | T | I | T | T | I | I | N | I | T | *T* | N | N | T | *T* | HI-A |
| Oakes | I | I | N | *I* | I | I | T | I | T | I | N | I | I | I | SI-A |
| Sam | M | *I* | M | T | M | I | M | M | M | *I* | M | N | M | *I* | SI-KA |
| Sandra | T | I | N | *I* | T | I | N | I | N | I | T | I | T | I | NI-A |
| Jasmine | T | I | N | I | N | T | N | *I* | I | I | N | I | T | I | KI-KA |

Italicized letters indicate the NOS aspects addressed in the lesson plan prepared after PCK for NOS instruction

*I* informed view, *T* transitional views, *M* missing data, *N* naive view, *HI-A* highly integrated in application level, *HI-KA* highly integrated in knowledge-application level, *HI-K* highly integrated in knowledge level, *SI-A* somewhat integrated in application level, SI-KA somewhat integrated in knowledge-application level, *SI-K* somewhat integrated in knowledge level, *NI-A* nonintegrated in application level about which they had transitional views (13 %) relied on their informed views throughout their planning.

## Interaction and Integration of Components of PCK

Although preservice teachers classified into the application subcategory were enabled to translate their PCK for NOS into their lesson plans, they were different from each other in terms of how successfully their lessons communicated NOS aspects. Preservice teachers whose PCK for NOS was well-developed and well-integrated were better able to create lessons to teach NOS. In the sections that follow, we highlight the cases of three participants, Grey, Florrie, and Fletcher, to illustrate the variation in their PCK integration and in the effectiveness of their lesson plans (Fig. 3).

Grey (see Fig. 3a) was oriented to teach NOS and included NOS objectives (i.e., nature of theory, law, and hypothesis) in her lesson plan in addition to chemistry-related objectives (i.e., polarity in covalent bonds). She provided evidence for consistency of her knowledge of learner, assessment, and instructional strategies with her NOS teaching orientation in her lesson plan. Those consistencies are indicated by bold lines in her map. Grey planned her lesson by considering students' difficulties and misconceptions about theory and law. In her lesson plan, she asked students to investigate valence theory as proposed by Gilbert Newton Lewis before the class session in which she teaches about polarity in covalent bonds. For this investigation, Grey gave students some questions to consider during their investigation, such as *What is the role of valence theory in explaining bonding*? *Why did Lewis call it as theory not the law*? *Can valance theory be a law*? At the beginning of the class, she had students share what they found. She explained that students' sharing their findings and ideas framed around these questions would help her understand difficulties and misconceptions that students have about theory and law. This part of the lesson plan is an indication of how Grey's knowledge of assessment informed her knowledge of learners (indicated by bold arrow pointing from assessment toward learner in Grey's map). After the sharing session, Grey conducted an explicit-reflective discussion considering expected students' misconceptions as follows:

> Grey (G): Why do we call it Lewis's *theory* although it sheds light modern chemistry? [aiming to elicit students' misconception, which is theory is not proved and not accepted by the scientific community therefore stays as theory, not become a law and does not play important role in science] and Can there be a Lewis Law?
> ESAs: (1) Since the truth of Lewis's theory is not proved, it is not called a law, (2) Since it is not directly observable, it remains a theory. For instance, evolution is a theory and it

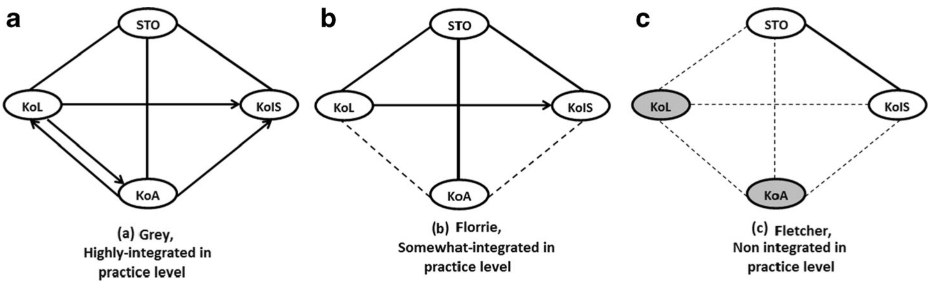



**Fig. 3 a–c** Three participants' maps from different degrees of integration subcategories in application level

is not observable too, and (3) The Lewis theory is not accepted by all of scientific community and therefore remains a theory and does not become a law.
G: There is a difference between the way we use the word theory in our daily life and the way it is used in science (scientific theory). If the truth of theories was not proved or theories were not accepted by most of the scientific community, we would not teach and learn in our chemistry or science classes.

Moreover, she was aware of one of the sources of misconceptions about the hierarchical relationship between theory and law (e.g., daily life usage of the words). Grey clarified this for students, and then gave several examples (e.g., evolution theory, gas laws, kinetic molecular theory) to explain the nature of theories-laws and the difference between them. She purposefully used an instructional strategy, asked specific questions, and gave key examples to remedy students' misconceptions about theory and law. This is an indication of how Grey's knowledge of learner informed her choice of instructional strategy (indicated by bold arrow pointing from learner toward instructional strategy in Grey's map). At the end of the class, she asked her students to investigate the concepts of scientific fact, theory, and law for the next class and be prepared to share. This is an indication of how Grey's knowledge of learner informed her knowledge of assessment (indicated by bold arrow pointing from learner toward assessment in Grey's map). By integrating her component knowledge bases of PCK, she was better-positioned to design a lesson that could address students' misconceptions about scientific theories and laws.

Florrie, whose PCK is somewhat integrated (see Fig. 3b), was similar to Grey. First, she had also consistencies between their orientation and learner, assessment, and instructional strategy (indicated by bold lines in Florrie's map). Florrie's lesson plan was on teaching electrochemical cells. Second, she was oriented to teach NOS and integrated NOS objectives in her plan (i.e., observation, inference, and difference between them). Also, Florrie was aware about students' difficulty in discriminating observation and inference. She planned guided-inquiry lesson to teach about NOS aspects in an explicit-reflective way and assessed her students' understanding about targeted NOS aspects at the end. However, Florrie was different from Grey in the sense that the only integration among the components of her PCK was between knowledge of learners and knowledge of instructional strategies. In her plan, she asked her students to make an electrochemical cell, run it, and write their observations and inferences. Florrie thought that this electrochemical cell observation would be useful to teach students observation, inference, and the difference between them. After completion of cells, students were to present their cells together with their observations and inferences. Then, she planned to conduct an explicit-reflective discussion on observation, inference, and the difference between them by asking *What are your observations*? *How did you observe*? *What are your inferences*? and *What is the difference between observation and inference*? This is an indication of how her knowledge of learner informed her knowledge of instructional strategy (indicated by bold arrow pointing from learner toward instructional strategy in Florrie's map). There was no evidence of integration between her knowledge of assessment and learners, however, nor assessment and instructional strategies. Florrie was not as successful as Grey, since she designed instruction to teach observation and inference without successfully aligning her NOS instruction and assessment with her knowledge of learners.

Fletcher, whose PCK is nonintegrated (see Fig. 3c), was similar to Grey and Florrie as he had a NOS teaching orientation, included NOS objectives (i.e., tentativeness and subjectivity) in his plans to teach acid–base theories, and used a history of science approach to teach NOS aspects in an explicit-reflective way. That is, his knowledge of instructional strategies was consistent with his orientation (indicated by bold lines in Fletcher's map). Fletcher had his students play the roles of Arrhenius, Bronsted-Lowry, and Lewis. After this, he planned to use discussion as an explicit-reflective strategy by asking *Why did acid–base theories change*? *Why did scientists need to develop different theories on the same phenomena*? and *Did scientists use their previous knowledge when developing their theories*? Unlike Grey and Florrie, Fletcher did not develop learner and assessment components of his PCK for NOS (indicated by gray filling in Fletcher's map), and consequently, he was not able to integrate those components with his orientation and instructional strategy. In his plan, he did not consider students' difficulties understanding theory, nor did he plan to assess what students already knew and learned during the lesson.

## Discussion

Currently, researchers have met with only limited success in supporting development of teachers' PCK for NOS (Akerson and Abd-El-Khalick 2003; Akerson and Volrich 2006; Faikhamta 2013; Schwartz and Lederman 2002). Helping *preservice* teachers develop PCK for NOS is additionally challenging, given that preservice teachers generally lack robust PCK associated with classroom teaching experience (Loughran et al. 2004). A limitation of PCK research conducted in teacher education contexts is that data more likely indicate "PCK readiness" (Davis 2003; Smithey 2003), consistent with the view that PCK is a construct consisting of understanding and enactment dimensions (Park and Oliver 2008). Thus, our first research question focused on examining the nature of preservice teachers' understanding in each of the component knowledge bases of PCK, and how these reflect their "PCK readiness." When we analyzed all participants' PCK for NOS map, we saw that knowledge of instructional strategies and science teaching orientation components were central to this integration. Furthermore, those PCK components were the only components that all participants could translate their knowledge into their lesson plans.

Our data clearly showed that pedagogical instruction framed by PCK for NOS tackled an important challenge—namely, helping preservice teachers internalize NOS as an important learning outcome and achievable by students (Abd-El-Khalick et al. 1998; Schwartz and Lederman 2002), and also this instruction fulfilled the lack of research on providing guidance for how to develop teachers' valuing of NOS (Lederman 2007). During the first session of this instruction, preservice teachers' orientations were elicited, in order that they become dissatisfied with these orientations as suggested by others (Aydin and Boz 2013; Brown et al. 2009). The intelligibility of new orientations that support NOS integration in classroom teaching practices was enhanced by developing an understanding of scientific literacy, the importance of it, and the role of NOS in achieving scientific literacy. The plausibility of new orientation was achieved by relating this orientation to teachers' existing science teaching orientations (e.g., daily life and correct scientific explanation). New orientations became fruitful for preservice teachers when they realized the applicability of it to all grades from kindergarten to university. Satisfying these conditions for conceptual change in preservice teachers' orientations may explain the change in their orientation to teach NOS and the reflection of that orientation in their planning.

Through participation in pedagogical instruction framed by PCK for NOS, all but three preservice chemistry teachers developed knowledge of instructional strategies effective for teaching NOS, and to a greater extent than any other components. This finding aligns with research indicating that teachers' development of instructional strategies is more prevalent than the development of other PCK components (Abd-El-Khalick et al. 1998; Bell et al. 2000; Hanuscin 2013). However, in contrast to prior studies (Bell et al. 2000; Hanuscin 2013), most of the preservice chemistry teachers in this study (22 out of 30) specifically assessed students' understanding of NOS, as evident in their lesson plans. Some researchers attribute teachers' inability to assess NOS to lack of knowledge of strategies for assessing students' NOS understanding (Hanuscin et al. 2011), while others view this as a discrepancy between teachers' practice and their belief in the importance of teaching NOS (Abd-El-Khalick et al. 1998). In both circumstances, our pedagogical instruction helped student teachers to align their beliefs with their practice and to increase their knowledge of assessment in terms of both what and how to assess. Participants were more successful in translating their knowledge of assessment (22 out of 30) and instructional strategies (30 out of 30) into their lesson plans than they were in translating their knowledge of learners into their lessons (16 out of 30). Several studies have documented similar findings about teachers' knowledge of learners. A study by De Jong and Van Driel (2001) reported that even in-service teachers did not have concerns for students' learning. Other studies have shown that preservice teachers do not consider students' ideas in their practice adequately (Park and Chen 2012; Tabachnick and Zeichner 1999). One factor influencing this study could be that participants did not have the chance to implement their lesson plans in real classrooms; therefore, they were not able to translate their knowledge of learners into their lesson plans as they do other PCK components. This is supported by research by Abell (2007) that emphasizes knowledge of learners improves with teaching experience.

The analysis of preservice chemistry teachers' postintervention PCK for NOS maps revealed a developmental progression in participants' PCK from knowledge about how to teach NOS (knowledge level) to translation of that knowledge in their lesson design (application level). That is, although participants developed particular knowledge components of PCK for NOS, not all were translated into lesson plans. Our findings lend further support to the view that PCK is a construct consisting of understanding and enactment dimensions (Park and Oliver 2008) and reflect earlier findings that "…increased knowledge in a single component may not be sufficient to stimulate change in practice." (Park and Chen 2012, p. 939).

Another possible explanation for why preservice teachers were unable to translate PCK components into their planning may be related to their relatively low efficacy (Aydin and Boz 2013; Park and Oliver 2008). Since preservice teachers lack teaching experiences, they typically have relatively low efficacy, and therefore, inability to enact PCK components may be expected. Despite the differences in our preservice teachers' PCK for NOS, pedagogical instruction framed by PCK for NOS was helpful to them in developing their professional practical knowledge for teaching NOS. This knowledge serves as the building blocks of their future PCK and can be thought of their PCK readiness (Davis 2003; Smithey 2003).

*Our second research question* examined the extent to which preservice teachers integrated their understanding within various subcomponents of PCK as they developed science lessons. Our findings demonstrate that pedagogical instruction framed by PCK for NOS enhanced preservice teachers' PCK readiness (i.e., knowing and applying PCK components) and, to some extent, put these pieces together (i.e., integrate components of

PCK), which are two steps toward developing rich and usable PCK (Smithey 2003). Interestingly, however, we found that having more informed views about NOS did not necessarily lead to having more integrated PCK for NOS. Yet, a closer look at the data showed that the vast majority of preservice chemistry teachers chose to include in their lesson plans the NOS aspects about which they had informed views. This indicates that some comfort in preservice chemistry teachers' own understanding of NOS is prerequisite to teaching NOS. It is important to consider, however, how successfully preservice teachers designed a lesson plan to teach the specific NOS aspect they chose. We found preservice teachers whose PCK for NOS was well-developed and well-integrated were better able to create appropriate lessons to teach NOS. This finding is compatible with the idea that the integration among the various subcomponents is necessary for robust PCK, which is the key to successful teaching (Friedrichsen et al. 2009; Magnusson et al. 1999; Park and Chen 2012).

The lesson plans constructed by our participants prompt questions regarding the nature of PCK for NOS. PCK is generally viewed as being topic-specific (van Driel et al. 1998), and researchers have asserted that NOS is analogous to other topics a teacher may teach (Lederman 1998). It logically follows that teachers would then have topic-specific PCK for different topics, including NOS. Yet, cases in which participants planned to teach NOS embedded within science topics defy this characterization. For example, Howard prepared a lesson on atomic theories and Fletcher designed a lesson on acid–base theories. While they had different PCK for these different chemistry topics, both of them used explicit-reflective instructional approaches to teach about the nature of theories. That is, the two drew on different PCK specific to the topics of atomic theories and acid–base theories, but both drew on PCK for teaching the nature of theories. Nonetheless, it stands to reason that teaching about the nature of theories within these two contexts (acid–base theories and atomic theories) would differ. At this point, an argument proposed by Davis et al. (2008) provides a useful way for conceptualizing this intersection. Davis et al. (2008) advocated that "…[w]hile PCK is typically conceptualized as topic-specific, teachers also need discipline-specific knowledge about how a discipline works" (p. 6). Moreover, Davis and Krajcik (2005) defined PCK for disciplinary practices as "teachers must know how to help students understand the authentic activities of a discipline, the ways knowledge is developed in a particular field, and the beliefs that represent a sophisticated understanding of how the field works (p. 5). Davis et al. (2008) illustrated their argument by discussing how discipline-specific PCK for scientific modeling includes "…knowledge of instructional strategies that can promote students' engagement in modeling practices and learning of metamodeling knowledge…[as well as] teacher's knowledge of their students' ideas and the challenges students face, again associated with modeling practices and metamodeling knowledge" (p. 6). Thus, teachers need to develop specific knowledge of modeling (PCK for scientific modeling) but might apply that within the context of teaching different topics. In this study, the discipline-specific PCK perspective helps explain preservice teachers' NOS teaching practices across different science topics. While preservice teachers developed knowledge of various aspects of NOS and PCK for teaching those aspects of NOS, this PCK for NOS intersects teachers' PCK for teaching other topics in the planning and implementation of instruction through topic-specific representations and activities that address both the targeted aspects of NOS and the focus science concepts.

## Implications

In this study, we found that NOS instruction followed by pedagogical instruction framed by PCK for NOS was effective in stimulating preservice chemistry teachers to integrate NOS into their chemistry teaching. This suggests that deliberate and purposeful efforts to target specific elements of preservice teachers' PCK may be more effective than approaches focused solely on *how to teach NOS* (i.e., teaching explicit-reflective instruction) that are commonly described in the literature. This also suggests value in providing coherence and connection across preservice teachers' coursework in terms of NOS. To foster the development of PCK for NOS, teachers should be provided with the opportunities where they study NOS as learners (developing an understanding of NOS) but also from a teaching perspective. This can be realized by enacting an explicit PCK framework (e.g., Magnusson et al. 1999) in a course where NOS is taught. Moreover, our results indicate that individual PCK components should be revisited in a way such that teachers are able to see how those components connect with each other in the design of instruction. Teachers, especially preservice teachers, may have difficulty in seeing the relevance of PCK for NOS instruction to their teaching. Engaging in explicit-reflective discussions of PCK for NOS components (e.g., knowledge of learner, curriculum, and instructional strategy) and the way they connect these knowledge bases can address this. In addition to approaches used in our study, there are several examples of research using a PCK framework and tools for making PCK explicit such as CoRes and PaP-eRs (Hume and Berry 2010; Loughran et al. 2008). It stands to reason that utilizing CoRes and PaP-eRs on NOS, developed by experienced NOS teachers, could help novice teachers to develop PCK for NOS. However, further research is needed to substantiate the effectiveness of various approaches to supporting development of pre- and in-service teachers' PCK for NOS.

As more studies are being conducted in regard to teachers' PCK for NOS, further consideration should be given to the nature of PCK for NOS. Which level of specificity in conceptualizing PCK (e.g., topic-specific and disciplinary-specific) can best capture the way teachers enact their PCK for NOS? How does this differ within the context of content-generic and content-specific NOS instruction? Is topic-specific PCK (e.g., PCK for acid–base theories) a prerequisite for development PCK for NOS when teaching NOS embedded in content or vice versa? Studies that focus specifically on the interplay of teachers' discipline-specific and topic-specific PCK are needed.

As educational standards emphasize NOS as a curriculum component, consideration should be given as to not only the knowledge of NOS teachers need to understand NOS, but also the complex knowledge required to *teach* NOS. Policy documents such as the US *Next Generation Science Standards* have advocated that NOS be taught integrated with disciplinary core ideas, cross-cutting concepts, and science and engineering practices. How NOS is related to these three fundamental areas and the possible ways to integrate NOS should be explored. In addition, there needs to be more explicit and clear portrayal of how this would look in actual classroom practice. That is, there needs to be support in terms of models for how teachers can achieve the vision of the reforms in terms of helping students develop an understanding of NOS.

**Acknowledgments** We would like to thank the TUBITAK 1001 and 2014 support programs provided by The Scientific and Technological Research Council of Turkey.

# Appendix 1

| Nancy's Profile | |
|---|---|
| **Participant** | Nancy |
| **Topic** | Particulate nature of matter |
| **Science Teaching Orientation** | • Science, technology and decisions<br>• Correct explanation<br>• Everyday Coping/Understand world<br>• A Structure of science<br>• Self as explainer |
| **SPS Objectives** | Absent |
| **NOS objectives** | Tentative and cumulative nature of scientific knowledge; subjectivity and creativity and imagination in science |
| **Instructional Strategy** | 5E (inquiry) explicit-reflective content embedded<br>History of science |
| **Lesson Synopsis** | Nancy used 5E model in her lesson planning. Throughout her planning, she stated expected student answers (ESA) to her questions and designed her instruction based on these answers. In previous class, students learned that matter consists of mobile particles and there is space among particles. This class, students are going to learn the states of matter. As a pre-assessment she administered 10 questions true-false test to students. Three of the questions were directly related to nature of science; Definitions about the phases of matter is absolute, Scientists produces unchangeable knowledge since they do numerous test, Scientists claim that previous knowledge in the discipline is wrong since they do not like each other. The purpose of administering this test is to elicit students' misconception and design instruction considering students' misconception. In the engagement phase, Nancy collected the 10 questions true-false test and looked at them to see students' misconceptions. She informed students that in previous class they learned about particulate nature of matter and in this class they will look at the subsequent developments and what questions scientists searched for the answers. She made a power point presentation on the historical development using the question-answer method. During the presentation Nancy focused on the ideas and contributions of Thales, Anaximandros, Empedocles, Aristo, Kanada, Leucippu, Democritus, Epicurus, and Lucretius. In the explanation phase, she conducted an explicit-reflective discussion on tentative and cumulative nature of scientific knowledge. After presentation, Nancy (N) asked "Scientists thought and searched for the nature and states of matter throughout the history. If you consider this process for producing scientific knowledge, what are the things that stood out to you? Is there only one and only scientists studied on nature of matter? ESA: Lots of scientists worked on the same topic. N: What else? Did any of them use the already existing knowledge in the discipline? or Did scientists start to work over? ESA: Scientists used the previous knowledge available in the discipline produced by other scientists. N: Were the knowledge accepted as absolute or did they change over time? ESA: There was a change in scientific knowledge produced throughout history. Nancy communicated the cumulative and tentative nature of scientific knowledge and then she had students to watch a simulation of three states of matter. After students watched the simulations, they worked in groups and drew how particles situated in each state. Following the completion of group work, students presented their models by creative drama. Nancy conducted a whole class discussion on spaces among the particles and mobility of the particles in three states of matter. Also, she conducted an explicit-reflective whole class discussion on tentativeness, subjectivity and the role of creativity and imagination science by asking the questions of "Which one of |

| | |
|---|---|
| | the models about states of matter is true? One of the groups or animations? Why are there differences among the models? Did you use your creativity and imagination as well as your logic? In the explanation phase, she explained plasma state of matter and by this way she exemplified the tentativeness of scientific knowledge. Also, Nancy described solid, liquid, and gas states of matter in detail. In extend phase, she asked students to explain what are the microscopic changes occur in particulate level when a solid becomes liquid and then becomes gas. Also, Nancy asked students to give examples from daily life where we can see the compressibility of gases. In the evaluation phase, she asked students to draw a concept map providing the concepts about particulate nature of matter. Also, she asked students to prepare a poster on the areas on which particulate nature of matter shed light on and also, this poster should reflect their understanding of nature of science. |
| **Evidence for the components of PCK and connections among them** | 1. At the end of the lesson, students will be able to understand<br>a. the tentative nature of scientific knowledge<br>b. the cumulative nature of scientific knowledge<br>c. the subjectivity<br>d. the creativity and imagination in science<br>(Lesson Plan #2, objectives, Nancy) (STO)<br><br>2. As a pre-assessment she administered 10 questions true-false test to students. Three of the questions were directly related to nature of science; Definitions about the phases of matter is absolute, Scientists produces unchangeable knowledge since they do numerous test, Scientists claim that previous knowledge in the discipline is wrong since they do not like each other. The purpose of administering this test is to elicit students' misconception and design instruction considering students' misconception. (Lesson Plan #2) (KoA, KoL, KoIS)<br><br>3. Also, she asked students to prepare a poster on the areas on which particulate nature of matter shed light on and also, this poster should reflect their understanding of nature of science. (Lesson Plan #2) (KoA)<br><br>4. She made a power point presentation on the historical development using the question-answer method. During the presentation Nancy focused on the ideas and contributions of Thales, Anaximandros, Empedocles, Aristo, Kanada, Leucippu, Democritus, Epicurus, and Lucretius. In the explanation phase, she conducted an explicit-reflective discussion on tentative and cumulative nature of scientific knowledge. After presentation, Nancy (N) asked "Scientists thought and searched for the nature and states of matter throughout the history. If you consider this process for producing scientific knowledge, what are the things that stood out to you? Is there only one and only scientists studied on nature of matter? ESA: Lots of scientists worked on the same topic. N: What else? Did any of them use the already existing knowledge in the discipline? or Did scientists start to work over? ESA: Scientists used the previous knowledge available in the discipline produced by other scientists. N: Were the knowledge accepted as absolute or did they change over time? ESA: There was a change in scientific knowledge produced throughout history. (Lesson Plan #2) (KoIS)<br><br>5. After students watched the simulations, they worked in groups and drew how particles situated in each state. Following the completion of group work, |

students presented their models by creative drama. She conducted an explicit-reflective whole class discussion on tentativeness, subjectivity and the role of creativity and imagination science by asking the questions of "Which one of the models about states of matter is true? One of the groups or animations? Why are there differences among the models? Did you use your creativity and imagination as well as your logic? In the explanation phase, she explained plasma state of matter and by this way she exemplified the tentativeness of scientific knowledge. (Lesson Plan #2) (KoIS)

6. During the lesson that we learned how to teach nature of science, I learned that I can both teach chemistry and nature of science at the same time. I will not definitely use implicit approach since I do not think that students can learn nature of science by experiencing the science itself. For instance, in the lesson that we argued about misconceptions about nature of science using concept cartoons if you did not elicit and explicitly discussed about the misconceptions they would have been changed. There should be opportunities for students where they explicitly reflect and discuss on science, scientific knowledge, and scientific method. (post interview) (KoIS)

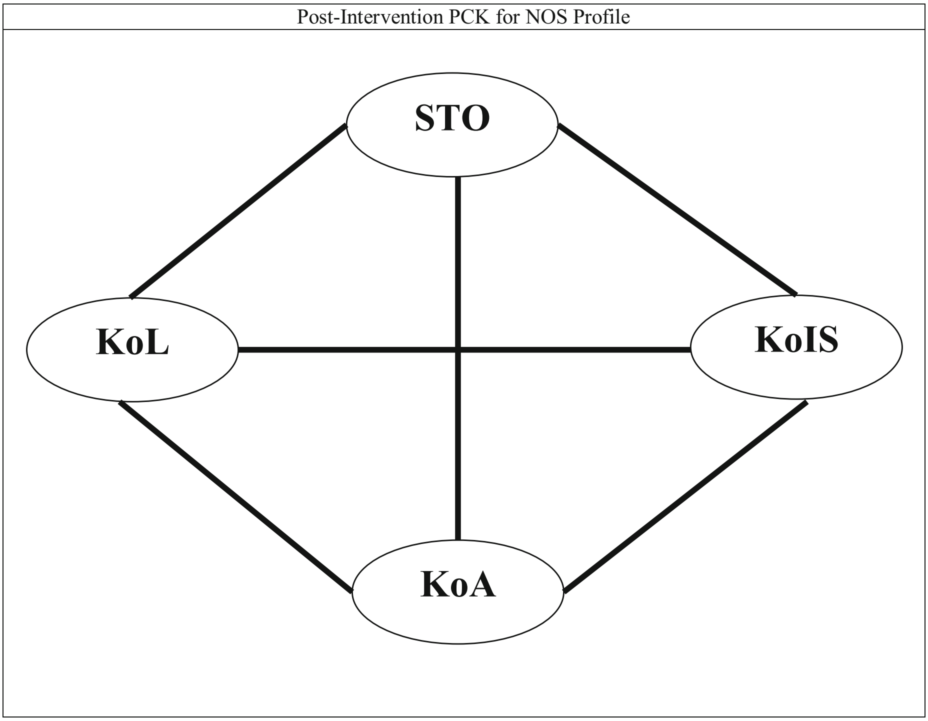
7. It is important to elicit students' misconceptions about nature of science for an affective nature of science instruction. If students believe that there is a universal and step by step scientific method or theories and laws do not change, my first goal should be create a conceptual change in students' mind instead of teaching about what theory or law is. After eliminating the misconceptions, the next step would be teaching about theory and law. Students' misconceptions can be identified through the use of concept cartoons, essay type questions. (post interview) (KoL, KoA, KoIS)

8. Instead of directly telling students that their belief about existence of universally accepted step by step scientific method is wrong, students should live and engage in the process of science and then teacher should conduct an explicit reflective discussion on the scientific method. (Reflection paper #5) (KoL, KoIS)

9. Concept maps, concept cartoons, and actvity sheets can be used to assess students' understanding about nature of science. (post interview) (KoA)

| | LP 2 | R1 | R2 | R3 | R4 | R5 | Interview |
|---|---|---|---|---|---|---|---|
| Description | After PCK for NOS | After STO | After KoL | After KoIS | After KoA | After PCK for NOS | After PCK for NOS |
| KoL | ✓ | | ✓ | | | ✓ | ✓ |
| KoA | ✓ | | | | ✓ | ✓ | ✓ |
| KoIS | ✓ | | | ✓ | | ✓ | ✓ |
| STO | ✓ | ✓ | | ✓ | | ✓ | ✓ |

✓ = present, O=absent; grey= missing data




## References


Abd-El-Khalick, F. (2013). Teaching with and about nature of science, and science teacher knowledge domains. *Science & Education, 22*(9), 2087–2107.

Abd-El-Khalick, F., & Boujaoude, S. (1997). An exploratory study of knowledge base for science teaching. *Journal of Research in Science Teaching, 34*(7), 673–699.

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.

Abd-El-Khalick, F., Waters, M., & Le, A. (2008). Representations of nature of science in high school chemistry textbooks over the past four decades. *Journal of Research in Science Teaching, 45*(7), 835–855.

Abell, S. K. (2007). Research on science teacher knowledge. In S. K. Abell & N. G. Lederman (Eds.), *Research on science teacher education* (pp. 1105–1149). New York: Routledge.

Abell, S. K. (2008). Twenty years later: does pedagogical content knowledge remain a useful idea? *International Journal of Science Education, 30*(10), 1405–1416.

Akerson, V. L., & Abd-El-Khalick, F. (2003). Teaching elements of nature of science: a yearlong case study of a fourth-grade teacher. *Journal of Research in Science Teaching, 40*(10), 1025–1049.

Akerson, V. L., & Volrich, M. L. (2006). Teaching nature of science explicitly in a first-grade internship setting. *Journal of Research in Science Teaching, 43*(4), 377–394.

Akerson, V. L., Abd-El-Khalick, F., & Lederman, N. G. (2000). Influence of a reflective explicit activity-based approach on elementary teachers' conceptions of nature of science. *Journal of Research in Science Teaching, 37*(4), 295–317.

Alters, B. J. (1997). Whose nature of science? *Journal of Research in Science Teaching, 34*(1), 39–55.

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy: a project 2061 report*. New York: Oxford University Press.

Aydin, S., & Boz, Y. (2013). The nature of integration among PCK components: a case study of two experienced chemistry teachers. *Chemistry Education Research and Practice, 14*(4), 615–624.

Baxter, J. A., & Lederman, N. G. (1999). Assessment and measurement of pedagogical content knowledge. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: the construct and its implications for science education* (pp. 147–161). Dordrecht: Kluwer Academic.

Bell, R. L., Lederman, N. G., & Abd-El-Khalick, F. (2000). Developing and acting upon one's conception of the nature of science: a follow-up study. *Journal of Research in Science Teaching, 37*(6), 563–581.

Brown P., Friedrichsen P., & Abell S. K., (2009, September). *Do beliefs change? Investigating prospective teachers' science teaching orientations during an accelerated post-baccalaureate program*. Paper presented at the European Science Education Research Association (ESERA) Conference, Istanbul, Turkey

Cavallo, A. (2008). Experiencing the nature of science: an interactive, beginning-of-semester activity. *Journal of College Science Teaching, 37*(5), 12–15.

Clough, M. P. (2006). Learners' responses to the demands of conceptual change: considerations for effective nature of science instruction. *Science & Education, 15*(5), 463–494.

Cochran, K. F., King, R. A., & De Ruiter, J. A. (1991, April). *Pedagogical content knowledge: a tentative model for teacher preparation*. Paper presented at the Annual Meeting of the American Educational Research Association, Chicago

Cochran, K. F., DeRuiter, J., & King, R. (1993). Pedagogical content knowing: an integrative model for teacher preparation. *Journal of Teacher Education, 44*(4), 263–272.

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

Creswell, J. W. (2003). *Qualitative inquiry and research design: choosing among five approaches* (2nd ed.). Thousand Oaks: Sage.

Davis, E. A. (2003). Knowledge integration in science teaching: analysing teachers' knowledge development. *Research in Science Education, 34*(1), 21–53.

Davis, E. A., & Krajcik, J. S. (2005). Designing educative curriculum materials to promote teacher learning. *Educational Researcher, 34*(3), 3–14.

Davis, E. A., Kenyon, L., Hug, B., Nelson, M., Beyer, C., Schwarz, C., & Reiser, B. J. (2008, January). *MoDeLS: designing supports for teachers using scientific modeling.* Paper presented at the Association for Science Teacher Education, St. Louis

De Jong, O., & Van Driel, J. (2001). The development of prospective teachers' concerns about teaching chemistry topics at a macro–micro-symbolic interface. In H. Behrednt, H. Dahncke, R. Duit, W. Graber, M. Komorek, A. Kross, & P. Reiska (Eds.), *Research in science education: past, present and future* (pp. 271–276). Dordrecht: Kluwer.

De Jong, O. D., Van Driel, J. H., & Verloop, N. (2005). Preservice teachers' pedagogical content knowledge of using particle models in teaching chemistry. *Journal of Research in Science Teaching, 42*(8), 947–964.

Dillon, J. (2009). On scientific literacy and curriculum reform. *International Journal of Environmental & Science Education, 4*(3), 201–213.

Dogan, N., & Abd-El-Khalick, F. (2008). Turkish grade 10 students' and science teachers' conceptions of nature of science: a national study. *Journal of Research in Science Teaching, 45*(10), 1083–1112.

Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young people's images of science*. McGraw-Hill International.

Faikhamta, C. (2013). The development of in-service science teachers' understandings of and orientations to teaching the nature of science within a PCK-based NOS course. *Research in Science Education, 43*(2), 847–869.

Flick, L. B. (1996). Understanding a generative learning model of instruction: a case study of elementary teacher planning. *Journal of Science Teacher Education, 7*(2), 95–122.

Fraenkel, J. R., & Wallen, N. E. (2006). *How to design & evaluate research in education* (6th ed.). Boston: McGraw-Hill.

Friedrichsen, P. J., Abell, S. K., Pareja, E. M., Brown, P. L., Lankford, D. M., & Volkmann, M. J. (2009). Does teaching experience matter? Examining biology teachers' prior knowledge for teaching in an alternative certification program. *Journal of Research in Science Teaching, 46*(4), 357–383.

Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory: strategies for qualitative research.* Chicago: Aldine.

Grossman, P. L. (1990). *The making of a teacher: teacher knowledge & teacher education*. New York: Teachers College Press.

Hanuscin, D. L. (2013). Critical incidents in the development of pedagogical content knowledge for teaching the nature of science: a prospective elementary teacher's journey. *Journal of Science Teacher Education, 24*(6), 933–956.

Hanuscin, D., Lee, M. H., & Akerson, V. (2011). Elementary teachers' pedagogical content knowledge for teaching the nature of science. *Science Education, 91*(1), 145–167.

Henze, I., van Driel, J. H., & Verloop, N. (2008). Development of experienced science teachers' pedagogical content knowledge of models of the solar system and the universe. *International Journal of Science Education, 30*(10), 1321–1342.

Hume, A., & Berry, A. (2010). Constructing CoRes—a strategy for building PCK in pre-service science teacher education. *Research in Science Education, 41*(3), 341–355.

Irzık, G., & Nola, R. (2010). A family resemblance approach to the nature of science for science education. *Science & Education, 20*(7–8), 591–607.

Jenny, K. (2011). Interactive relationships among teachers' intentions, beliefs, pedagogical content knowledge and classroom instruction on the nature of science. Unpublished doctoral thesis, University of Hong Kong.

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.

Kim, B. S., Ko, E. K., Lederman, N.G., & Lederman, J. S. (2005, April). *A developmental continuum of pedagogical content knowledge for nature of science instruction*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Dallas, Texas

Köseoğlu, F., Tümay, H., & Ustün, U. (2010). Developing a professional development package for nature of science instruction and discussion about its implementation for pre-service teachers. *Journal of Kırşehir Education Faculty, 11*(4), 129–162.

Lawson, A. (2002). Sound and faulty arguments generated by pre-service biology teachers when testing hypotheses involving unobservable entities. *Journal of Research in Science Teaching, 39*(3), 237–252.

Lederman, N. G. (1998). The state of science education: subject matter without context. *Electronic Journal of Science Education*, 3(2). Retrieved October 03, 2010 from http://ejse.southwestern.edu/original%20site/manuscripts/v3n2/articles/guest%20editorial/lederman.html.

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

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

Lederman, N. G., Schwartz, R. S., Abd-El-Khalick, F., & Bell, R. L. (2001). Preservice teachers' understanding and teaching of nature of science: an intervention study. *Canadian Journal of Science, Mathematics, and Technology Education, 1*(2), 135–160.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of the nature of science questionnaire: toward valid and meaningful assessment of learners' conceptions of the nature of science. *Journal of Research in Science Teaching, 39*(6), 497–521.

Lin, H., & Chen, C. (2002). Promoting pre-service chemistry teachers' understanding about the nature of science through history. *Journal of Research in Science Teaching, 39*(9), 773–792.

Loughran, J., Mulhall, P., & Berry, A. (2004). 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.

Loughran, J., Mulhall, P., & Berry, A. (2008). Exploring pedagogical content knowledge in science teacher education. *International Journal of Science Education, 30*(10), 1301–1320.

Lumpe, A. T. (2007). Research-based professional development: teachers engaged in professional learning communities. *Journal of Science Teacher Education, 18*(1), 125–128.

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.

Marshall, G. B., & Rossman, C. (2011). *Designing qualitative research* (5th ed.). London: Sage.

Matthews, M. R. (1998). In defense of modest goals when teaching about the nature of science. *Journal of Research in Science Teaching, 35*(2), 161–174.

McComas, W. F., & Olson, J. K. (1998). International science education standards documents. In W. F. McComas (Ed.), *The nature of science in science education rationales and strategies* (pp. 41–52). Dordrecht: Kluwer Academic.

McComas, W. F., Clough, M. P., & Almazroa, H. (1998). The role and character of the nature of science in science education. In W. F. McComas (Ed.), *The nature of science in science education: rationales and strategies* (pp. 3–39). Dordrecht: Kluwer Academic.

McDonald, C. V. (2010). The influence of explicit nature of science and argumentation instruction on preservice primary teachers' views of nature of science. *Journal of Research in Science Teaching, 47*(9), 1137–1164.

Miller, M. L. (2001). *Enriching pedagogical content knowledge of prospective chemistry teachers: how can the science methods course help?* Unpublished doctoral dissertation, Purdue University, Indiana, USA.

National Academy of Sciences. (1998). *Teaching about evolution and nature of science*. Washington: National Academy Press.
National Research Council. (2011). *A framework for K-12 science education: practices, crosscutting concepts, and core ideas*. Washington: National Academies Press.
Nilsson, P., & Loughran, J. (2012). Exploring the development of pre-service science elementary teachers' pedagogical content knowledge. *Journal of Science Teacher Education, 23*(7), 699–721.
Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschl, R. (2003). What ideas-about-science should be taught in school science? A Delphi study of the expert community. *Journal of Research in Science Teaching, 40*(7), 692–720.
Ozgelen, S., Hanuscin, D., & Yilmaz-Tuzun, O. (2013). Preservice elementary science teachers' connections among aspects of NOS: toward a consistent, overarching framework. *Journal of Science Teacher Education, 24*(5), 907–927.
Park, S., & Chen, Y. C. (2012). Mapping out the integration of the components of pedagogical content knowledge (PCK): examples from high school biology classrooms. *Journal of Research in Science Teaching, 49*(7), 922–941.
Park, S., & Oliver, J. S. (2008). Revisiting the conceptualization of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in Science Education, 38*(3), 261–284.
Patton, M. Q. (2002). *Qualitative evaluation and research methods* (3rd ed.). Thousand Oaks: Sage.
Pongsanon, K., Akerson, V. L., Park Rogers, M., & Weiland, I. (2011, April). *Exploring the use of lesson study to develop elementary preservice teachers' pedagogical content knowledge for teaching nature of science.* Paper presented at the National Association for Research in Science Teaching Orlando, Florida
Schwartz, R. S., & Lederman, N. G. (2002). It's the nature of the beast: the influence of knowledge and intentions on learning and teaching nature of science. *Journal of Research in Science Teaching, 39*(3), 205–236.
Shulman, L. S. (1986). Those who understand: knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.
Shulman, L. S. (1987). Knowledge and teaching: foundations of the new reform. *Harvard Educational Review, 57*(1), 1–22.
Smith, M. U., & Scharmann, L. C. (1999). Defining versus describing the nature of science: a pragmatic analysis for classroom teachers and science educators. *Science Education, 83*(4), 493–509.
Smith, M. U., Lederman, N. G., Bell, R. L., McComas, W. F., & Clough, M. P. (1997). How great is the disagreement about the nature of science: a response to Alters. *Journal of Research in Science Teaching, 34*(10), 1101–1103.
Smithey, J. (2003). *Two perspectives on expertise in elementary science teaching*. Ann Arbor: University of Michigan.
Tabachnick, B. R., & Zeichner, K. M. (1999). Idea and action: action research and the development of conceptual change teaching of science. *Science Education, 83*(3), 309–322.
Taber, K. (2008). Towards a curricular model of the nature of science. *Science & Education, 17*(2–3), 179–218.
Tamir, P. (1988). Subject matter and related pedagogical knowledge in teacher education. *Teaching and Teacher Education, 4*, 99–110.
van Driel, J. H., Verloop, N., & de Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching, 35*(6), 673–695.

## Notes

This material is based upon work supported by The Scientific and Technological Research Council of Turkey 1001-Scientific and Technological Research Project Support Program under Grant 108K086 entitled "Teaching the Nature of Science: Production of a professional development package for teaching scientific argumentation and reasoning based on philosophy and history of science."