Chemistry Education:
Research and Practice

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Cite this: DOI: 10.1039/c0xx00000x

www.rsc.org/xxxxxx

ARTICLE TYPE

A science faculty's transformation of nature of science understanding into his teaching graduate level chemistry course

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Received (in XXX, XXX) Xth XXXXXXXXX 20XX, Accepted Xth XXXXXXXXX 20XX

DOI: 10.1039/b000000x

This is an interpretive case study to examine the teaching of an experienced science faculty who had a strong interest in teaching undergraduate and graduate science courses and nature of science specifically. It was interested in how he transformed knowledge from his experience as a scientist and his ideas about nature of science into forms accessible to his students. Data included observations (through the 12-week semester) and field notes, Views of Nature of Science-Form B, as well as semi-structured interview. Deductive analysis based on existing codes and categories was applied. Results revealed that robust SMK and interest in nature of science helped him address different nature of science aspects, and produce original content-embedded examples for teaching nature of science. Although he was able to include nature of science as a part of a graduate course and to address nature of science myths that graduate students had, nature of science assessment was missing in his teaching. When subject matter knowledge and nature of science understanding support each other, it may be a key element in successful nature of science learning and teaching. Similar to science teachers, the development of assessment of nature of science may take more time than the development of other components of instruction (i.e., instructional strategy) for science faculties. Hence, this result may be an indication of specific need for support to develop this component of teaching.

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Introduction

The ultimate goal of science education all around the world is to raise a scientifically literate society (Abd-El-Khalick, Waters, & Le, 2008; Lederman, 2007). There are different definitions of what scientific literacy is (DeBoer, 2000), however, they share some aspects that are related to developing learners' science knowledge, knowledge about scientific processes, nature of science, and use scientific knowledge in daily-life. "It highlights the key distinction between an education that prepares students for a career as a professional scientist, engineer or technician and an education that focuses on wider citizenship goals." (Hodson, 2009, p.1) To be a scientifically literate citizen, understanding of basic science concepts, nature of science (NOS), and science-technology-society relationship are necessary (National Research Council [NRC], 1996; Shamos, 1995). In this sense, achieving scientific literacy requires teaching NOS as well as teaching science content (Lederman, 2007). NOS has been an important aspect stressed out in the curriculum documents (e.g., National Ministry of Education, [NME], 2013; NRC, 1996; The Next Generation Science Standards, Achieve, Inc., 2013) (Dillon, 2009). To achieve the goal of science education, NOS should be part of the science courses and taught from primary to tertiary level. Science education literature has mostly focused on NOS teaching at elementary and secondary levels (e.g., Akerson & Donnelly, 2010; Khishfe, & Abd-El-Khalick, 2002; Morrison, Raab, & Ingram, 2009). Due to dearth of research on science faculties' NOS teaching (Karakas, 2011), this research digs into a science faculty's transformation of his experience into teaching NOS at a graduate chemistry course.

Literature Review

In the literature, different definitions of NOS have been existed. A detailed definition of NOS was provided by McComas, Clough and Almazroa (2002) in their inspirational work as following:

The nature of science is a fertile hybrid arena which blends aspects of various social studies of science including the history, sociology, and philosophy of science combined with research from the cognitive sciences such as psychology into a rich description of what science is, how it works, how scientists operate as a social group and how society itself both directs and reacts to scientific endeavors (p.4).

Regarding the aspects of NOS, different sources provided different lists. In this study, the list released by National Science Teacher Association [NSTA] (2000) was utilized. In NSTA's list, tentative, theory-laden, imaginative and creative, empirical NOS, the difference between observation and inference, and the relations between laws and theories were stated as important aspects of NOS.

Table 1. Aspects of NOS stated in NSTA (2000)

NOS Aspects	Description of the aspect
Tentative nature of science	Scientific knowledge may be changed by the use of new knowledge and technology or the re-interpretation of the existent data.
There is no single scientific method used in scientific inquiry	Different methods can be used in different disciplines. Also, they can be used in the same discipline but with different objectives. Scientists generally do not follow the same steps.
Imagination and creativity in science	Scientists' creativity and imagination play an important role in the all steps of scientific research
Empirical basis of science	Science based on the new scientific information gathered through observation, experiments, and other scientific ways.
Inferential/theoretical nature of science	Inference is an important part of scientific knowledge generation. The data accumulated through observation and experiment should be interpreted.
Subjectivity in science	The scientists' previous life, experiences, and expectations, experience, previous knowledge, and beliefs may effect scientists' observation, inference, and interpretation.
Theory and law difference	With adequate evidence, theories do not become laws. Their nature is different. Theory has an explanatory nature whereas law has a descriptive and predictive nature for the relationships and patterns.
Socio-cultural embeddness of science	The social, political, and religious features of a society in which scientists work have an influence on scientists' research regarding what to study.

To integrate NOS into teaching, NOS understanding and subject matter knowledge (SMK) are required. However, it is not an automatic process through which teachers transfer NOS understanding into practice (Lederman, 2007). Therefore, teachers should develop pedagogical content knowledge (PCK) described as the knowledge that teachers should possess to make the topic more understandable for learners (Shulman, 1986). In Shulman's view, which was influenced by Schwab's idea (1964) (as cited in Abell, 2007), SMK has two parts, namely, substantive SMK and syntactic SMK. Science teachers should have knowledge about scientific principles, theories, and concepts (i.e., substantive SMK) in addition to knowledge about scientific inquiry, and how scientific knowledge is produced and refused (i.e., syntactic SMK). In other words, syntactic SMK is used for knowledge about NOS.

According to Magnusson, Krajcik and Borko (1999), PCK has five components, (table 2), namely, science teaching orientation (STO) (i.e., teachers' beliefs and knowledge about goals of science teaching), knowledge of curriculum (KoC) (i.e., knowledge about curricular goals), knowledge of learners (KoL) (i.e., learners' difficulties), knowledge of instructional strategies (KoIS) (i.e., subject specific- strategies and activities), and knowledge of assessment (KoA) (i.e., how to assess).

Table 2. Description and explanation of PCK components for teaching NOS

PCK components	Description of the components for teaching NOS	Explanation of the components for NOS teaching
Science teaching orientation (STO)	Teachers' knowledge and beliefs about the goals of science education for a particular group of learners	Believing in teaching NOS, integrating NOS into the course and teaching it is necessary for scientifically literate society
Knowledge of curriculum (KoC)	Knowledge about curricular goals and materials	Making NOS an important aspect of the graduate course syllabus and being aware of the materials for successful NOS teaching
Knowledge of learner (KoL)	Knowledge about learners' difficulties, misconceptions, and prior knowledge about NOS and its aspects	Learners generally think that theories become laws with evidence. Learners have difficulty in understanding the tentative nature of scientific knowledge. Learners might/ might not take NOS course earlier.
Knowledge of instructional strategy (KoIS)	Knowledge about instructional strategies and activities for teaching NOS	Using Black Box activity for teaching the difference between observation and inference.
Knowledge of assessment (KoA)	Knowledge about assessment of learners' understanding of NOS	Using concept cartoons for assessing learners' understanding about NOS and its aspects

For an effective NOS integration into science courses, teachers need to develop PCK for NOS. "PCK is not a fixed body of knowledge but instead an ability that can be developed through reflection and application. "(Fernandez-Balboa & Stiehl, 1995, p. 294) Therefore, teachers should focus on what they teach, how their teaching helps learners, and make required changes in the instruction when necessary.

Research on Teaching NOS

If science teachers are supposed to integrate NOS into their teaching, they should be accompanied with explicit (i.e., overt and purposeful NOS teaching including use of the instructional strategies and assessment) NOS instruction in the teacher education programs. NOS can be taught in different ways. Table 3 shows them and provides explanations.

Table 3. NOS instruction

Dimensions	Types	Explanation	Example
Emphasis	Explicit-reflective	Teaching NOS through mentioning NOS aspects explicitly	Using Rutherford's Gold Foil experiment to discuss about the difference between observation and inference and organizing a class discussion about what observation is and what the inference is
	Implicit	Teaching NOS through making learners participate science activities	Making learners perform a laboratory activity and expecting them understand the difference between observation and inference
Relation to Content	Content-embedded	Teaching NOS aspects though integrating them the content taught	Teaching tentative nature of scientific knowledge in Atomic Models topic and relate tentativeness with the changes in the atomic theories from Dalton to Modern Atomic Theory
	Content-generic	Teaching NOS aspects without integrating them into the content taught	Teaching subjectivity aspect of NOS by using 'young or old?' activity in which a picture is shown to learners. Teacher asks them what they see.

Research has stated that explicit-reflective teaching is more useful for learners to understand NOS than implicit approach (Abd-El-Khalick & Lederman, 2000a; Akerson, Hanson, & Cullen, 2007; Lederman, 2007). Both content-embedded and content-generic activities were found helpful for learners to comprehend NOS (Lederman, 2007). In addition to those, history of science (HOS) can be supplemented into NOS teaching, which uses interesting cases of scientific developments in the history. In a study focusing on using HOS for NOS teaching, Lin and Chen (2002) stated that HOS augmented learners' NOS understanding. In the post treatment interviews, researchers observed that participants in the treatment group used historical cases to explain their NOS understandings.

Regarding the factors influencing NOS teaching, Morrison, Raab, and Ingram (2009) stated that sharing scientists' experiences, having previous experience about scientific research, and professional development activities that used explicit-reflective approach were very effective for developing teachers' NOS understanding. Similarly, Hodson (2009) identified that having involvement in a scientific discipline helps teachers develop rich NOS understanding. Parallel to Hodson's statement (2009), Anderson and Clark (2012) revealed that the participant elementary science teacher's inadequate experience in scientific inquiry resulted in limited connections to substantive SMK to develop syntactic SMK that is NOS understanding. Hence, she utilized her general pedagogical knowledge that is not specific to science teaching to develop syntactic SMK for teaching science.

Teaching NOS literature has had many studies on K-12 students' NOS understanding and K-12 teachers' NOS teaching

(Abd-El-Khalick, et al., 2008). However, relatively few studies attempted to dig into science faculties' teaching NOS in science content courses at the teacher education programs both at undergraduate and graduate levels (Karakas, 2009, 2011; Lederman, 2007). Karakas (2009) focused on four science faculties' NOS teaching in undergraduate courses. Analysis of the data showed that all cases preferred to teach NOS in a teacher-centered way, which is related to their desire to cover more topic. Only one of the cases observed utilized HOS to teach NOS, Large class-size, and inadequate teaching and management skills were the factors influencing negatively their teaching NOS. In another study, Karakas (2011) studied 17 college science faculties' NOS understanding. Results revealed that participants had a sophisticated, idea about one NOS aspect whereas they had a naïve view about the others. Karakas concluded that participating in scientific research does not entail an informed NOS view for scientists.

Research on science faculties' teaching would be beneficial (Fernandez-Balboa & Stiehl, 1995). Focusing on their NOS teaching "could help us understand how NOS might be taught in these classrooms and how to better communicate NOS to students, so that we can graduate more informed students and teachers" (Karakas, 2011, p. 1125). Science faculties teach in a very different context than K-12 teachers do. First of all, science faculties have strong SMK that is a mediating factor for teaching NOS (Scwartz & Lederman, 2002). Additionally, they do not feel pressure of covering the content as much as K-12 teachers do. Yet another point is conducting scientific research and being a part of the scientific community may or may not help faculties develop an informed NOS view (Kuhn, 1970). Participating in scientific research does not guarantee for informed epistemological assumptions and/or nature of the process. Finally, in general, science faculties receive little preparation for teaching (Berry & van Driel, 2013), much less preparation for teaching NOS than K-12 teachers do (e.g., Akerson, Abd-El-Khalick, & Lederman, 2000; Akerson & Donnelly, 2010; Akerson, Hanson, & Cullen, 2007; Eastwood, Sadler, Zeidler, Lewis, Amiri & Applebaum, 2012; Hanuscin, Lee, & Akerson, 2011; Khishfe & Abd-El-Khalick, 2002). Faculties' integration of NOS into their teaching has advantages (McComas, et al., 2002). College students may get benefit of learning NOS. Additionally, students who want to be a teacher have a chance to observe how to teach NOS. However, having an experience in scientific research does not mean that faculties are eager to teach it in accurately. To answer those points arisen, this study was conducted in a chemistry course offered to graduate students in graduate school of education.

Significance of the study

In the NOS literature research has focused on science teachers' teaching NOS (Akerson et al., 2007; Hanuscin et al., 2011), teacher educators' teaching NOS in the context of science teaching methods course (Abd-El-Khalick & Akerson 2004), and in physics course for preservice science education majors in a college (Hanuscin, Akerson, & Phillipson-Mower 2006). In those studies the instructors and teachers had an informed training on NOS (Bautista & Schussler, 2010). Due to scarcity of research on faculties' teaching NOS, this study examined a science faculty's (i.e., in this study a professor who used to be a part of scientific community for a long time, George , pseudonym) NOS teaching. Recently, he has been interested in teaching undergraduate and graduate science courses. He has been to both sides of the field (i.e., both a former scientist and a science instructor who is interested in teaching chemistry). Longitudinal research on science faculties' understanding and beliefs about NOS, and how they reflect those into their practice would be helpful in how knowledge and beliefs, and different sources shape their practice (Karakas, 2011). Although Karakas (2009, 2011) studied with science faculties' understanding and teaching NOS, the participants of the studies were not interested in NOS, research in teaching NOS, and HOS. In this study, however, George, is motivated to read about NOS, philosophy and HOS, which makes this study different than the previous ones. Additionally, this study is also significant regarding the nature of PCK for NOS is an area deserving further investigation (Lederman, 2007). Therefore, it was attempted to examine how a science faculty transforms his previous experience as a scientist, and his recent experience in NOS into teaching of a graduate chemistry course.

Methodology

Research Design

This study is an interpretive case study to examine a science faculty member's nature of science (NOS) teaching in a graduate chemistry course (Patton, 2002). The case was a chemistry professor teaching chemistry in a science teacher education graduate program. Regarding studying with only one case is a limitation of this study. However, it should be considered that not many science faculties are aware of NOS and its teaching. Moreover, they are not very much eager to teach NOS at gradate level, which is a limiting factor for studying with many cases.

The Context

This study took place in a graduate course offered to graduate students. The course was a three-credit elective content course. For this study, George was purposefully selected (Patton, 2002) due to his experience both in scientific research, teaching chemistry, and interest in teaching and learning NOS. He pursued a career in pure chemistry. He was a practicing chemist for a long time (more than a decade) and later decided to teach chemistry in a chemistry teacher education program (i.e., both at undergraduate and graduate levels) in a college of education. His interest in NOS, which he has pursued through reading (i.e., NOS articles, philosophical books, etc.) began about five years ago.

Data Collection

Data included observations and field notes, as well as semi-structured interview. George's teaching graduate course was observed through the 12-week semester. The researcher observed his teaching for 12 weeks and took detailed notes about his teaching, NOS aspects mentioned, the examples from history of science (HOS) that he provided. At the end of the semester, we conducted a semi-structured interview for the purpose of exploring George's understanding of NOS, pedagogical content knowledge (PCK) for teaching NOS, and to probe his underlying reasoning regarding specific instances of his NOS teaching (See Appendix for the examples of interview questions) The interview took two hours and was audiotaped then transcribed verbatim for analysis. Additionally, to determine his NOS understanding level, Views of Nature of Science-Form B (VNOS-B) (Abd-El-Khalick, Bell, & Lederman, 1998; Bell, 1999) (see Appendix for an example item from VNOS-B) was administered as an interview protocol. Due to George's concerns, videotaping was not used, which is a limitation of the study. However, the researcher took very detailed notes about his teaching, graduate students' questions, and the classroom discussions.

Data Analysis

In the first phase of analysis, the data were read and coded deductively according to Magnusson et al.'s PCK model (1999) (see table 2) and NOS aspects (see table 1) and teaching NOS (see table 3). Field notes and interview data were coded for each PCK components. Then, the parts of the each component were put together in a table. Later, for sub-components (e.g., misconceptions, difficulty, and prior knowledge of students) of the PCK components were separated for detailed analysis. In other words, deductive analysis were conducted for each PCK elements for teaching NOS. Table 4 shows an example of the data coding for knowledge of instructional component of PCK.

Table 4. Data analysis example for knowledge of instructional strategy component of PCK

PCK component: Knowledge of instructional strategy	Type of the strategy used		
	Content-relatedness	Explicit vs. Implicit	NOS aspect / myth addressed
HOS Neill Barlett: Reactions of Nobel gases	Content-embedded	Explicit	Tentative nature of scientific knowledge
Content specific examples created by George: Acid strength of Oxy acids of Halogens	Content-embedded	Explicit	Myth-5: "Evidence accumulated carefully will result in sure knowledge" (McComas (2002, p.58)
Discussion: How is it possible to draw orbitals shape without seeing them?	Content-embedded	Explicit	Experimentation is not the only method used to acquire knowledge. Scientists also use mathematics and equations

Two researchers who have experience in qualitative research, NOS, and chemistry teaching coded the data independently. The codes were compared and the interrater reliability was calculated as .87 (Miles & Huberman, 1994). Coders met to resolve discrepancies and discussed on them till they had consensus. Observations and filed notes were triangulated by the use of the interview data (Patton, 2002). Data and investigator triangulation, and long-term observation (i.e., 12 weeks) were used to ensure the trustworthiness of the results (Patton, 2002). Additionally, before the study, George was informed about the purpose of the study. He agreed to participate in the research. To protect the participant's anonymity, some of the information about him (e.g., name, the graduate course taught, and the participant's field) was hidden. A pseudonym, George, was used. Finally, after analysing the data, he was invited for member-check. The results were shared with him. He agreed with the interpretation of the data collected and analysed.

Results

Results will be presented for George's NOS view and then his PCK for NOS teaching by the use of PCK model suggested by Magnusson and her colleagues' (1999). Detailed examples will be provided to help reader understand George's teaching NOS at graduate content course.

George's NOS view

According to his answers to the questions from VNOS-B, George has a well-informed NOS view, which means that his answers to the questions were consistent with the literature on NOS. For instance, in VNOS-B there was a question about the tentative nature of scientific theories. When asked, George explained his view in detail:

> The root of the 'theory' is Greek. It means speculation. However, we should not understand that theories are weak due to their nature… If we want to talk about a theory from chemistry, we can focus on Kinetic Molecular Theory of gases that explains how gas particles behave and the reason of why they do. Can theories change? Of course they can. Philosophers of science use history of science to explain the tentative nature of scientific knowledge. They choose their examples from history of science. For instance, Phlogiston Theory that was replaced by Lavoisier's Combustion theory. Similarly, atomic theories: Dalton, Thompson, Rutherford, Bohr, and now Modern Atomic theory (Interview)

His all answers to the VNOS-B questions were parallel to the consensus view of NOS aspects. Additionally, as can be seen from the passage above, he is able to provide examples from HOS and chemistry field. To conclude, he had an informed NOS understanding for all NOS aspects. Therefore, his answers to other VNOS-B questions were not provided here. In the following part, George 's PCK for NOS will be presented.

Science Teaching Orientation (OST)

Regarding the reasons why he integrated NOS into his teaching George stated three goals. First, he believed that teaching NOS helps learners to understand science and remember the content taught.

> One of the main problems in the education system is neglecting teaching NOS although it is important… I mean that educators have stated that it [NOS] is a part of science. If we do not mention it in the courses than it means that we do not believe in that. So, I try to teach it as much as I can in my courses. If I know anything about historical or philosophical aspect of the topic taught, I mention it. I think it help learners to remember. For instance, I always talk about the Tin pest 2when I teach Tin. I have observed that that assists learners'

[2] Tin pest (also known as tin disease) is an allotropic transformation of tin at low temperatures. Tis pest is related to story of medieval Europe especially in church pipe pieces and Napoleon's' button in Russian campaign in

remember the transformation of tin (Interview)

Second, he stated that when he talks about the people who contributed scientific knowledge, he aimed at making learners think that science is a human endeavor. During the semester, he mentioned that Balmer who studied on spectral line emissions of hydrogen was a teacher and Paul Héroult, a high school student who proposed a method of electrolysis of aluminium. With those examples, he intended to encourage graduate students to do scientific research and to believe in themselves. Finally, concerning about his goals of teaching NOS, he mentioned that many of the graduate students taking the course are teachers at high schools. Hence, he wanted to be a role model for teaching about NOS. He stated that teaching NOS to 10 high school teachers might result in teaching NOS at least 1000 high school students.

Knowledge of Curriculum (KoC) for teaching NOS

At tertiary level, curriculum is different than at primary and secondary level. Faculties prepare their own syllabus for a specific course. Hence, in this study, syllabus prepared by George for this graduate course was taken under the knowledge of curriculum component, which is a modification made to Magnusson and her colleagues' PCK model in this study. In the original model, KoC is described regarding the curricula. However, at the tertiary level science faculty prepares their own curricula for the courses that they teach. Due to that reason, it is appropriate to modify KoC with that way.

At the beginning of the semester, he stated the areas on which he would focus through the semester, namely, (a) the historical development of the element concept, (b) the Periodic Table: the classification, and the similarities among the groups and the rationale behind the classification, (c) the discovery and the isolation of the elements, and their physical and chemical properties (Field note, week-1). First two ones helped him incorporate NOS into the syllabus. Through the semester, it was observed that he addressed the NOS aspects (Field notes) (Table 5).

the mid 1800s. George told both stories in his course.

Table 5. NOS aspects and myths mentioned by George through the semester

NOS aspects mentioned in the course	Frequency
Tentative nature of scientific knowledge	6
Socio-cultural embeddness of science	1
Subjectivity in science	2
Empirical nature of science	4
There is no single method of science	2
Science is a human endeavor	2
Creativity and imagination in science	2
Evidence accumulated carefully will result in sure knowledge (Myth 5 from McComas et al., 2002)	1
Science models represent the reality (Myth 13 from McComas et al., 2002)	1
Science is amoral	2

Knowledge of Learners' (KoL) difficulties and misconceptions about NOS

Difficulties

Regarding learners' difficulties in learning NOS and myths that they have, George had a strong understanding of the reasons why students possess them. When asked in the interview, s/he told that students' existent paradigm and the inconsistencies between instructors' teaching (i.e., some faculties were unaware of the NOS and its aspects) were the main sources of the struggle.

> Researcher (R): What are the possible reasons of the difficulties of learners in understanding NOS?
>
> George (G): Their existing believes.... Let's say their paradigm from Kuhnian perspective. When they heard that there is no single scientific method, they start to think that whether it is correct or not. Especially the first time they heard it... Also, if they never think that scientists may not be completely objective, they have many questions. They start to question existing and new knowledge.

In addition that he stated that learning about NOS is difficult due to inconsistency among the faculties' teaching. Some of the other faculties teach with a positivist philosophy, which makes his NOS teaching less effective (interview).

Prior knowledge

In terms of prerequisite knowledge for learning NOS, he thought that students taking his class should know what philosophy is, what philosophical knowledge is, and the difference between scientific and philosophical knowledge. He stated that when he realized that students had not taken philosophy course earlier, he devoted some time on introducing what philosophy is, how philosophers work, and science-philosophy relation. Additionally, he also mentioned the common myths that students have (e.g., theories become law with more evidence). Through the semester, he also mentioned some of the myths in the class (e.g., scientists are particularly objective) and addressed them by the use of specific examples from history of chemistry/science and examples that he produced by the use of his SMK (i.e., a specific example was provided in misconceptions part below)

Misconceptions (Myths)

Finally, regarding the misconceptions that learners generally have, he stated that most of the students thought that scientific knowledge (i.e., especially laws) cannot be changed, scientists are completely objective, and all scientists use a particular method. In the course observed, George addressed all those misconceptions during the semester (see table 5). For instance, he talked about the tentativeness of scientific knowledge and gave the non-stoichiometric compounds3 (e.g., TiH0.9) to show that law of constant proportions and law of definite proportions may not be used to explain those compounds structure. George stated that before the invention of the non-stoichiometric compounds, scientists thought those laws explained the composition of all compounds. Then, they came to understand that it is useful for only some parts of the compounds.

Knowledge of Instructional Strategies (KoL) Implemented for teaching NOS

George utilized traditional teacher-centered teaching through the semester for both teaching other part of the content covered in the course and NOS. He implemented discussion and history of science (HOS), however, he did not apply any specific activity (e.g., 'young or old' activity to address the subjectivity in science) stated in the literature to teach NOS.

Regarding the content-relation of his instruction on NOS, he mentioned the NOS aspects and explained them in the context of the topic (field notes). The examples he provided were generally related to the content taught, which shows that they are content-embedded. To be specific, he was talking about the orbitals and their shape. He stated that scientists has not been able see the atom yet and asked how the representation of orbitals' shape could be given in the science textbooks. He took graduate students' ideas about how that is possible to represent a phenomenon without seeing it. At the end of the discussion, George highlighted that in scientific inquiry, experimentation is not the only method used to acquire knowledge. He stressed that scientists also use mathematics and equations.

Another point considering his knowledge of instructional strategy (KoIS) for teaching NOS was that he was able to address more than one NOS aspect by the use of a story from HOS or a content-embedded example. To illustrate, when he was teaching Noble Gases, he told the story of how Neill Bartlett recognized how close the ionization energies of oxygen molecule (i.e., he was working on it) and Xenon. Then he conducted research on it and stated that Noble gases also form compounds. In this example from HOS, George addressed both creative-imaginative NOS and tentative NOS aspects by the use of HOS.

Yet another point deserving attention in George 's instruction was that he generated many of the examples he used for teaching NOS. In addition to examples and activities in the NOS literature, he created useful examples from chemistry content. For example, when teaching the Halogens' oxyacid compounds, he mentioned that Bromine, Iodine, and Chlorine have a full series of oxyacid (i.e., from HBrO to HBrO4), However, when this knowledge is generalized to all halogens, it creates problem because Fluorine does not have full series of them. This example produced by him to address the myth-5 in McComas (2002), namely, "evidence accumulated carefully will result in sure knowledge" (p.58). When asked in the interview, he stated: "You can theoretically guess the oxyacid of Fluorine and say that Fluorine should form oxyacid. Yet, you have to check it. It is hypothetical deduction…. I support Popper's swan example with this halogen example". Another example was related to subjectivity (i.e., theory-laden) in science. He stated that scientist' beliefs, theories, and culture in which they live may have an influence on their interpretation and observation. Then he stated that in General Chemistry laboratory course; there was a lab activity about calculating sulphur's atomic mass. When students calculated molar mass of as about is 256.8 grams, some of them who are not aware of the structure of sulphur (i.e., S_8) were surprised and then checked sulphur's molar mass from the periodic table. Then students reported that they calculated it as 32 g/mol without explaining why they received it. George stated that their previous knowledge about sulphur affected them. He related this interesting example that he faced with in his previous course with subjectivity aspect of NOS. As seen from the provided examples, he took advantage of his substantive SMK to produce content-embedded examples of NOS aspects.

Regarding the use of his previous (i.e., conducting research as a chemist) and recent experiences (i.e., teaching chemistry as at undergraduate and graduate level), he stated:

> I have been to both sides. So, I feel comfortable about teaching nature of science [NOS]. I think, when I was a scientist, I was not able to realize the [NOS] aspects. For example, Thompson proposed a model, and so did Rutherford[4]. I could not

[3] **"[t]he law of definite proportions states that a chemical compound always contains exactly the same proportion of elements by mass. An equivalent statement is the law of constant composition, which states that all samples of a given chemical compound have the elemental composition. According to this law, the proportion of elements by mass for all compounds should not have any change irrespective of their origin, existence form, preparation, and determination methods…. Although the law of definite proportions is very useful in the foundation of modern chemistry, it is not true universally." (Xu, Pang, & Huo, 2011, p.321)**

[4] **Both Thompson and Rutherford used alpha scattering published by Geiger and Marsden who studied with Rutherford. Although they used the same data, they came up with different explanations of the alpha scattering. "Thomson propounded the hypothesis of compound scattering, according to which a large angle deflection of an alpha particle**

understand what it means. I mean I could not recognize its [scientific knowledge's] tentative nature. I never asked that when they proposed them, what is wrong with the existent one. I used to think that I know the atomic theories but I did not know why we teach all of them, which is a self-criticism for myself. But I feel lucky because at least I am aware of it [NOS] now. There are many science faculties who still teach like I used to teach ten years ago (Interview)

When asked the sources that helped him learn NOS and its teaching, he stated that reading books and research papers about NOS helped him integrate NOS into his courses. George has been incorporated NOS into his other courses since he started to learn about NOS.

Knowledge of Assessment (KoA) of learners' NOS understanding

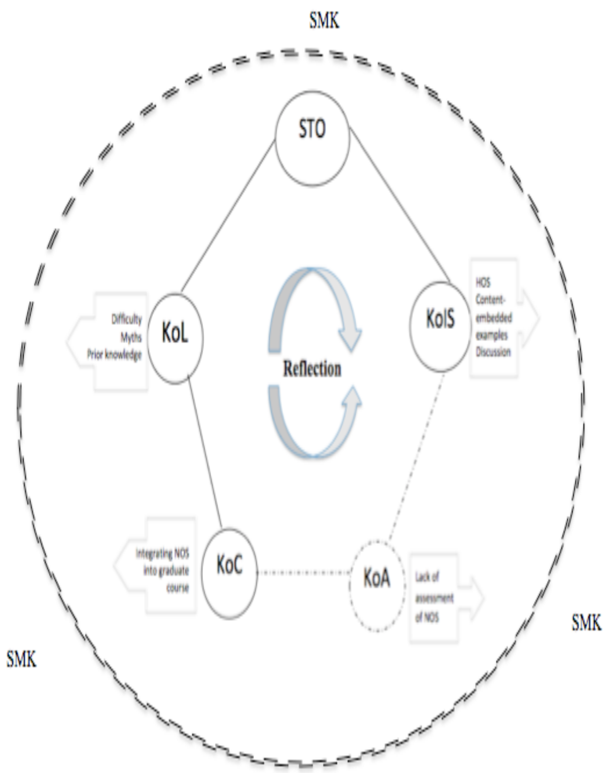
Although George incorporated NOS into his teaching, he did not assess graduate students' NOS understanding neither in mid-term nor final exams. The exams were traditional paper-pencil tests including items about the structure of the elements, their reactions, acidity of the oxy acid compounds, etc. When asked the reason why he did not assess NOS understating, he said that the course was not a specific NOS course, therefore, he did not focus on assessing NOS understanding in the exams. Regarding assessment aspect of his teaching, it was interesting that he took graduate students' ideas about the integrating NOS into the course. Although he overlooked assessing NOS in the exams, he took feedback about his teaching from the participants. In the interview, he stated that graduate students' reactions were positive towards NOS integration. Additionally, some of the students who were chemistry teachers at high schools used those examples and HOS stories in their teaching as well, which motivated him to integrate NOS into the course.

To conclude, George was aware of importance of integrating NOS into the chemistry content course at graduate level. Hence, he integrated NOS into his course syllabus (KoC). During the semester, he addressed graduate students' misconceptions about NOS, helped them understand the points that are difficult for them, and tried to understand whether learners had course on NOS or philosophy. Additionally, he was able to teach NOS by the use of HOS, discussions, and content-embedded examples from chemistry field. With help of solid NOS understanding and rich subject matter knowledge (SMK), he created new examples to address NOS aspects and misconceptions. However, George did not assess students' NOS understanding in the course. Although assessment was not focused in the course, he took graduate students' ideas about his teaching. With help of the students' ideas and his observations, he stated that teaching NOS is important in science courses in addition to content covered.

resulted from successive collisions between the alpha particles and the positive charges distributed throughout the atom. Rutherford in contrast, propounded the hypothesis of single scattering, according to which a large angle deflection resulted from a single collision between the alpha particle and the massive positive charge in the nucleus" (Niaz & Maza, p.7, 2011)

Figure 1 summarized George's pedagogical content knowledge (PCK) for teaching NOS in the graduate chemistry course.

Figure 1. George 's PCK for teaching NOS



Conclusion & Discussion

In this study, a former science faculty's NOS teaching in a graduate content course was examined by the use of Magnusson et al.'s PCK model. George 's teaching was teacher-centered and traditional, which is parallel to his didactic science teaching orientation (STO). It is consistent with the PCK literature stating that STO has a shaping effect on teachers' practice (Magnusson et al., 1999). Second, although s/he paid attention to NOS in her/his syllabus and highlighted it through the semester, s/he did not assess to what extend students develop their NOS understanding. Hanuscin et al. (2011) received the similar uneven development of PCK for NOS of elementary science teachers. Hanuscin et al. (2011) criticized that research has paid attention to teaching NOS but overlooked how to assess it. Given the importance of reading on George's learning how to integrate NOS into her/his course, this result is expected. Therefore, how to and what to assess NOS have to be focused on the research on NOS teaching. Additionally, the literature revealed that the development of knowledge of assessment (KoA) might take more time than the development of other components (Hanuscin et al., 2011; Henze, van Driel, & Verloop, 2008). Regarding this point, it is also important that although the faculty could develop KoC, KoL, and partly KoIS for teaching NOS, KoA was nonexistent, which may an indication of specific need for support to develop this component of PCK.

Similar to Hanuscin, et al., (2006), Karakas (2011), and McComas et al. (2002), although the faculty engaged in scientific research for a long time, he could not develop an informed NOS view. "[E]ven scientists who have better training in scientific investigations and who are involved with scientific research on day to day basis are still confused with this aspect of NOS, as much as students and teachers are." (Karakas, 2011, p. 1147) As George stated in the interview, he came to understand NOS with help of the NOS literature rather than working as a scientist. This point makes us relate it with implicit approach for teaching NOS, which assumes that learners can learn nature of scientific knowledge and processes by participating inquiry activities without explicit discussions or attention. Research has revealed that implicit approach is not effective as explicit approach (Khishfe & Abd-El-Khalick, 2002; Lederman, 2007). Similar to implicit approach used in NOS teaching, participating into scientific inquiry as a scientist neither contributed to George's NOS understanding nor help him develop an informed NOS understanding. However, when he started to read about NOS, its aspects, and teaching NOS, he realized that he did not use to have a critical view of science, scientific knowledge, and scientific inquiry.

Finally, regarding robust SMK and teaching NOS relation, in our case, rich and deep chemistry SMK allowed George to produce different content-embedded examples from chemistry to address NOS aspects. Shulman (1987) described PCK as ''the special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding'' (p. 8). In other words, SMK is one of the main sources necessary for effective teaching. For better and deeper NOS teaching, SMK is prerequisite and plays a prominent role. Regarding this point, Lederman (2007) argued: "[t]he teacher with more extensive subject-matter background, who also held a more well-developed understanding of NOS, was better able to address NOS throughout his teaching." (p. 856) To conclude, when SMK and NOS understanding support each other, it may be a key point in successful NOS learning and teaching, which provides useful implications for science teaching and NOS. In this case, George combined his substantive SMK and syntactic SMK, which were available for him to develop PCK for NOS. A contrasting example in Anderson and Clark's (2012) case (i.e., an elementary science teacher) general pedagogical knowledge was combined with her syntactic SMK, which were available for the elementary science teacher with weak substantive SMK.

Implication

From the results presented, it is obvious that science faculties should be supported regarding how to integrate NOS into courses. As George stated, many of his colleagues are still teaching without being aware of NOS. Although our case partly achieved this through his own effort and with help of robust SMK, it could be stated that both faculties working at science education, and science and art departments should have a dialogue on what NOS is, and how to teach it. Karakas (2009) recommended that "having a better communication between the two will make both of them are aware of each others goals and concerns while teaching" (p.117). To make it possible, the workshops, weekly-seminars on NOS teaching, and even NOS courses may be offered to science faculties. As seen in George case, realizing the importance of NOS is vital for integrating NOS into teaching. Hence, this communication may be started with introducing NOS, the aim of integrating it into science courses. After achieving that, details for learners' difficulties, teaching activities, and assessing NOS understanding should be focused in the meetings of the both groups. It is important to understand that science educators will take advantage of this dialogue too. As seen in the George's teaching, owing to dialogue between the two groups, distinctive examples and HOS cases can be created with help of the science faculty who work in different fields (e.g., biology, astronomy). Sharing some time and energy on the issues will result in productive and novel examples for teaching NOS, and addressing NOS myths that learners have.

The literature on NOS has been dominated by the studies conducted with teachers and K-12 students. Conversely, science faculties are left alone in how to teach NOS at tertiary level. Some of them also used to engage in an authentic scientific inquiry, however, we little know about how and to what extend they incorporate the past experiences into NOS teaching. This study aimed to answer those questions and to fill this gap in the literature. Those faculties' students are pre-service science teachers who are the teachers of the future or graduate students some of whom are teaching science at schools. Paying more attention to faculties' NOS understanding and teaching is supposed to result in better-trained graduate students and science teachers, who have responsibility of raising scientifically literate citizens.

Notes and references

† Electronic Supplementary Information (ESI) available: [details of any supplementary information available should be included here]. See DOI: 10.1039/b000000x/.

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APPENDIX

Example Item from VNOS-B

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

Example Questions from Interview

Science Teaching Orientation

Lead-off Question: Why do you incorporate NOS into the class?
What were your purposes for pointing out NOS?
Why is it important for graduate students to learn about NOS?

Knowledge of Instructional Strategies

Lead-off Question: What are the teaching strategies that you use to help students develop an understanding of NOS?
Which strategies did you use to teach NOS in this class?

Knowledge of Learners

What are the difficulties related to teaching NOS?
Why do you think is teaching NOS difficult? What are the factors making teaching it difficult?

Can you tell me about which difficulties do students have while learning NOS?
Which myths/misconceptions may students have related to NOS?

Knowledge of Curriculum: Making explicit NOS in the syllabus

Lead-off Question: Why is NOS mentioned in the syllabus?
How do you decide to integrate NOS into the topics taught in this course?
How did you decide to teach NOS in this course? What were the factors motivating you to stress NOS in the class?

Knowledge of Assessment

Lead-off Question: How do you assess to what extent students understand NOS?
Which assessment techniques do you use to assess their understanding in NOS?

Other Factors:

As an inorganic chemistry professor, you have a rich and deep chemistry content knowledge. How does your content help you teach/incorporate NOS into your classes?
You conducted research in inorganic chemistry for many years. As a scientist, how does your research experience in chemistry help you develop your NOS understanding? When you learnt NOS aspects suggested by international curriculum documents, did you have any disagreement with any NOS aspects (e.g. tentativeness, subjective NOS, etc.). If yes, could you please tell me the details about why did you have those experience?

An Example of Questions asked to Clarify George's NOS Teaching

During teaching aluminum production, you mentioned to Martin Hall and Paul Héroult, a high school student, and how they proposed a method of electrolysis of aluminum. By using this story, which aspect of NOS did you want to emphasize?