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Influence of Teachers' Conceptions of the Nature of Science on Classroom Practice

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Whether teachers' conceptions of NOS are reflected in their instructional planning and classroom practice remains an important research question. Consequently, this study investigated teachers' NOS views and their relationship to their classroom practice and delineated the factors that facilitate or impede this relationship. To achieve this, seven high school biology teachers with teaching credentials were selected to participate in this study. These teachers filled out an open-ended questionnaire entitled Views of the Nature of Science Questionnaire, participated in semi-structured interviews, were videotaped, and their lesson plans were collected. Results showed that most teachers do not possess appropriate NOS views, lesson plans lacked any planning for teaching NOS, and teachers' practices lacked any explicit reference to the aspects of NOS.

Keywords: multiple solution method; nature of science, classroom practices, biology teaching

INTRODUCTION

Developing scientifically literate individuals is one of the important goals in recent science education reform efforts and thus, a central component of science education curricula (Dillon, 2009; Osborne & Dillon, 2008; Roberts, 2007). Concurrently, acquiring scientific literacy necessitates the emphasis on understanding the Nature of Science (NOS). Lederman (1999) argues that when individuals understand NOS, they become more informed about science and the scientific enterprise and thus are empowered to make educated decisions about science-related issues. Science education reform documents (e.g. NRC, 1996) and science education researchers (e.g. Bell, Lederman, & Abd-El-Khalick, 2000; Lederman, 1999) have identified the following common aspects of the scientific enterprise: Science is tentative, a product of human creativity, empirically based, subjective, involves human inference, imagination, and creativity, and is socially and culturally embedded. One additional aspect is related to the relationship between theories and laws and the function of each, this aspect has not been addressed sufficiently in reform documents but is of equal importance to the previous ones (Lederman, 1999).

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Considerable work has been done to determine the factors influencing the acquisition of different aspects of NOS. The impact of teachers' conceptions of NOS on their instructional practices and thus, on their students' understanding of this construct has been investigated in various research studies (e.g. Abd-El-Khalick, Bell, & Lederman, 1998; Brickhouse, 1990; Lederman, 1999; Waters-Adams, 2006; Aslan & Taşar, 2013). Brickhouse (1990) found that teachers' knowledge about NOS, no matter in line with standard aspects set by science educators or not, mediated an explicit translation of this knowledge into classroom practice. On the contrary, Lederman and Zeidler (1987) found that teachers' classroom behavior is not a direct implication of their conceptions but is mediated by a variety of variables. In fact, a growing area of research maintains that "the

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State of the Literature

- Developing scientifically literate individuals is one of the important goals in recent science education reform efforts and thus, a central component of science education curricula.
- When individuals understand NOS, they become more informed about science and the scientific enterprise and thus are empowered to make educated decisions about science-related issues
- Teachers' knowledge about NOS, whether it is in line with standard aspects set by science educators or not, mediated an explicit translation of this knowledge into classroom practice

Contribution of this paper to the literature

- NOS aspects were neither planned for nor taught in the classrooms, except for implicit instances for teaching the empirical NOS. reasons for this stae of affairs included congested curriculum, textbooks that do not empahsize NOS, lack of time, and assessment criteria and practices that do not emphasize NOS.
- Even though all teachers had taken courses that emphasized NOS, the views of NOS were still lacking indicating the need to change the approaches used in teaching NOS in teacher preparation programs

relationship between teachers' conceptions and their classroom practices is far from being direct or simple" (Abd-El-Khalick, Bell, & Lederman, 1998, p. 419; Aslan & Taşar, 2013).

Teachers' Conceptions of NOS and their Effect on Practice

Various researchers have attempted to establish the relationship between teachers' conceptions of NOS and their classroom practices (Abd-El-Khalick, Bell, & Lederman, 1998; Bartholomew, Osborne, & Ratcliffe, 2004; Brickhouse, 1990; Bell, Lederman, & Abd-El-Khalick, 2000; Aslan & Taşar, 2013). Schwartz and Lederman (2002) emphasized that, depth of understanding of the aspects of NOS as well as knowledge of the subject-matter content knowledge are of practical importance in guiding the teachers' instructional practices in their classrooms.

In Lebanon, a summary of the research about NOS by "BouJaoude and Abd-El-Khalick (2004) reveals that NOS research is of two types: Descriptive studies and intervention studies. Farah (1994) showed that teachers did not have an adequate understanding of NOS aspects which are, according to the researcher, a direct result of the failure of university programs to introduce these aspects to pre-service science teachers. Moreover, while interviewing science teachers and school administrators regarding their views of science, BouJaoude and Abd-El-Khalick (1995) reported that teachers' thought of science as content without any regard to other important aspects. Similarly, BouJaoude (1999) found that most teachers and students hold traditional views of NOS and argued that the origin of these views stems from the emphasis on science content and the neglect of the epistemology and sociology of science in the Lebanese curriculum. Abd-El-Khalick (2001) carried out an intervention study whose results revealed that teachers acquired adequate and contemporary conceptions but were still incapable of transferring their knowledge into new teaching contexts. Likewise, Abd-El-Khalick, Bell, and Lederman (1998) asserted that despite possessing the knowledge framework of NOS, teachers did not explicitly refer to its aspects in either their planning or instruction. Bell, Lederman, and Abd-El-Khalick (2000) also found that pre-service teachers in their study failed to identify the aspects of NOS among the instructional objectives they aimed to achieve despite the fact that their conceptions of NOS were appropriate. A similar conclusion was drawn by Lederman and Zeidler (1987) who maintained that "A teacher's classroom behavior does not necessarily vary as a direct result of his/her conceptions [about the NOS.]" (p.73). Concurrently, there are other factors which should be investigated to enlighten teacher educators about the intricacies existing in actual classrooms. An important factor to be investigated is the possession of the appropriate pedagogical content knowledge necessary for teaching the aspects of NOS.

Nature of Science Pedagogical Content Knowledge (NOS PCK)

According to Bartholomew, Osborne, and Ratcliffe (2004) it is essential that teachers develop their own appropriate knowledge of the aspects of NOS and the scientific processes before they can effectively address these in their classrooms. Abd-El-Khalick and Lederman (2000a, 2000b) suggested that teachers should possess what they called 'NOS PCK', suggesting that for teachers to be able to teach NOS in their classrooms, they not only need to possess the appropriate knowledge of NOS but also the necessary pedagogical content knowledge relative to NOS. Moreover, Schwartz and Lederman (2002) highlighted the importance of weaving subject-matter knowledge, NOS knowledge, and pedagogical knowledge for teachers to successfully address NOS aspects in their classrooms. All three knowledge areas should interact and coalesce in order to develop the NOS PCK. Thus, the factors necessary for teachers to teach NOS appropriately include understanding NOS, PCK of

NOS along with other classroom factors which are discussed below.

A number of studies (e.g. Abd-El-Khalick, Bell, & Lederman, 1998; Duschl & Wright, 1989; Lederman, 1995, 1999; Lederman & Zeidler, 1987; Aslan & Taşar, 2013) have reported that factors such as viewing NOS as less significant than other instructional outcomes, classroom management, lack of resources, lack of teachers' experience, lack of planning time, intention to teach NOS, pressure to cover content, and perceptions of students all come together to impede or facilitate the alignment between NOS conceptions and classroom practice. Correspondingly, Lederman (1999) and Bell, Lederman, and Abd-El-Khalick (1997), claimed that many factors contribute to the translation of conceptions into classroom practices, some of which include teachers' level of experience, intentions, and perceptions of students. Bell, Lederman and Abd-El-Khalick (1997), argued that for appropriate translation of NOS conceptions into classroom practice, teacher preparation programs should instill among preservice teachers an understanding of the importance of teaching NOS and stressing it in their instructional strategies in classrooms.

Similarly, Abd-El-Khalick and BouJaoude (1997) reasoned that teacher preparation programs are not facilitating the development of the suitable conceptions related to the aspects of NOS as outlined by Lederman (1992). In their study, teachers were found to hold naïve and incoherent ideas related to NOS and thus, the researchers recommended reforming education preparation programs to enhance the development of the appropriate knowledge base that includes NOS and NOS-PCK necessary for adequate teaching practices.

The above findings underscore the claim that helping students develop appropriate NOS concepts is a complex process that requires careful thinking and targeted planning. Research has shown that even though teachers might have adequate conceptions of NOS, they do not seem to make use of this knowledge to provide their students with the appropriate NOS conceptions. Moreover, as outlined above, research in Lebanon has focused mainly on teachers' conceptions of NOS. Consequently, the purpose of this study is to examine the possible relationship between conceptions and practices in Lebanon science classrooms and to determine the factors that mediate this relationship.

Specifically, the following research questions guide this investigation:

(1) How do teachers' conceptions influence their practices about NOS?

(2) What are the factors that mediate the relationship between conceptions and practice?

METHODOLOGY

Research Design and Participants

A qualitative design was employed in this study in order to capture the meanings teachers construct about their experiences. Seven grade-10 high school biology teachers from private secondary schools in Beirut participated in this study. These teachers were implementing the Lebanese science curriculum, one of whose aims is to prepare scientifically literate individuals who understand NOS (BouJaoude, 2002). Moreover, the teachers were using the grade-10 biology national textbook which reflects the Lebanese curriculum and thus would be expected to have the potential to introduce NOS. All participant teachers held bachelors degrees (BS) in biology in addition to a teaching diploma (TD) in science for secondary school level. The Teaching Diploma in science/secondary is a post-BA one-year program that prepares its holders to teach biology, chemistry, or physics at grades 7-12. Having the TD guarantees that teachers had studied NOS during their teacher preparation programs and possess adequate pedagogical as well as content knowledge.

Data Sources

For triangulation purposes, various sources were used for data collection including a questionnaire entitled "Views of Nature of Science Questionnaire (VNOS-C)", interviews, videotaped classroom observations, and lesson plans.

Views of Nature of Science Questionnaire (VNOS-C)

The "Views of Nature of Science Questionnaire" (VNOS-C) (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) was utilized to assess teachers' conceptions of NOS. VNOS-C is a modified and expanded version of the original VNOS questionnaire (Abd-El-Khalick, Lederman, Bell, & Schwartz, 2001). VNOS-C is an open-ended questionnaire comprised of ten items with the purpose of elucidating students' views about several aspects of NOS including empirical, tentative, inferential, creative, theory-laden and social and cultural NOS. In addition, it addresses the myth of the "Scientific Method", and the distinction between scientific theories and laws. Content validity of the items in this questionnaire was established by Abd-El-Khalick et al. (2002). It is important to note that there is no one-to-one correspondence between the items in the questionnaire and the NOS aspects. The questionnaire was piloted with a science education graduate student who had no problems completing it.

Table 1. NOS Aspects and Their Definitions (Schwartz, Lederman, & Crawford, 2004)

Aspect	Description
Tentativeness	Scientific knowledge is subject to change with new observations and with the reinterpretations of existing observations. All other aspects of NOS provide rationale for the tentativeness of scientific knowledge.
Empirical basis	Scientific knowledge is based on and/or derived from observations of the natural world.
Subjectivity	Science is influenced and driven by the presently accepted scientific theories and laws. The development of questions, investigations, and interpretations of data are filtered through the lens of current theory. This is an unavoidable subjectivity that allows science to progress and remain consistent, yet also contributes to change in science when previous evidence is examined from the perspective of new knowledge. Personal subjectivity is also unavoidable. Personal values, agendas, and prior experiences dictate what and how scientists conduct their work.
Creativity	Scientific knowledge is created from human imaginations and logical reasoning. This creation is based on observations and inferences of the natural world.
Observations and inference	Science is based on both observation and inference. Observations are gathered through human senses or extensions of those senses. Inferences are interpretations of those observations. Perspectives of current science and the scientist guide both observations and inferences. Multiple perspectives contribute to valid multiple interpretations of observations.
Sociocultural embeddedness	Science is a human endeavor and is influenced by the society and culture in which it is practiced. The values of the culture determine what and how science is conducted, interpreted, accepted, and utilized.
Laws and theories	Theories and laws are different kinds of scientific knowledge. Laws describe relationships, observed or perceived, of phenomena in nature. Theories are inferred explanations for natural phenomena and mechanisms for relationships among natural phenomena. Hypotheses in science may lead to either theories or laws with the accumulation of substantial supporting evidence and acceptance in the scientific community. Theories and laws do not progress into one and another, in the hierarchical sense, for they are distinctly and functionally different types of knowledge.

Videotaping

The same teachers who completed the questionnaire were videotaped twice in their classrooms. The length of each videotaping was 50 minutes and the videotapes were then transcribed for subsequent analysis. The purpose of videotaping was to identify instances of teaching NOS and the variables that mediate the teaching of the aspects of NOS including teachers' instructional practices, the overall classroom atmosphere, use of rote learning, problem solving, higher level questions, as well as presenting knowledge as testable, developmental, unified, etc. (Lederman & Zeidler, 1987).

Individual interviews

Semi-structured interviews were used to validate teachers' views of NOS expressed in the questionnaires and elucidate and clarify these views (Appendix I). During these interviews, a process of stimulated recall was used during which each teacher was provided with her/his own filled-out questionnaire and was asked to read, explain, and justify her/his responses. Such questions allowed the researchers to assess the views and positions held by the teachers, clarify the reasons behind expressing such views, and delineate the factors that mediate or hinder the translation of these into classroom practices. The questions used in the interviews were adopted from Abd-El-Khalick, et al. (2001).

Lesson plans

Each teacher was asked to submit a minimum of two lesson plans. These lesson plans were used to identify any instances of NOS during planning for instruction. In summary, data included 7 questionnaires, 14 videotaped sessions, 7 individual interviews, and 17 lesson plans from 7 teachers teaching biology in 6 private schools.

Data Analysis

Data from each teacher were analyzed separately in order to generate individual profiles. This involved searching data for evidence of use of the different aspects of NOS. Then comparisons were made between the individual teacher profiles to identify similarities and differences. Finally, data from the different sources were analyzed to find out if the views from the different sources were aligned. In order to validate the analysis, a graduate student majoring in science education met with one of the researchers to discuss the data analysis process and reach a common understanding of this process, then the graduate student analyzed sections of the data independently but concurrently with one of the researchers. Following this step, the student and the researcher met to compare results and clarify differences. This process was repeated several times until almost complete consensus was reached between the student and the researcher. Subsequently, one of the researchers completed the data analysis.

Analysis of responses to the VNOS-C and individual interviews

Teachers' views about NOS were elucidated by the use of the VNOS-C questionnaire and the individual interviews. The interviews were given priority when explicating teachers' views regarding NOS because they provided teachers with the opportunity to elaborate and justify their responses. Moreover, these interviews helped to clarify teachers' opinions about the factors that facilitate or hinder the translation of their NOS views into classroom practices. Comparisons between the teachers' views and the NOS aspects were generated by using the descriptions of NOS aspects described in Lederman (1992) and Schwartz, Lederman, and Crawford (2004) as shown in Table 1. A teacher's view was categorized as either naïve or informed based on the comparisons with the NOS aspects. If the teacher's view was in line with the standard aspects of NOS as set by Lederman (1992), then such a view was considered informed. On the contrary, if the view was not in accordance with the standard definitions of the NOS aspects, it was termed naïve.

Analysis of videotapes and lesson plans

All references to the aspects of NOS in the transcripts of the videotapes and lesson plans, whether implicitly or explicitly addressed, were documented. NOS aspects were considered to be explicitly addressed when they were obviously and overtly introduced in classroom activities or in objectives presented in the lesson plans. On the other hand, these aspects were considered to be implicitly addressed when they were "inferred from less prominent parts of the data sources" (Abd-El-Khalick et al., 1998, p.422).

A coding system was used to analyze the data obtained from the various data sources. To refer to the participants, a numbering code was used from 1 to 7 preceded by the letter 'T' which stands for 'teacher'. To refer to the information obtained from the VNOS-C questionnaire, interview, lesson plan, or videotapes, the following abbreviations were used: "VNOS", "Int.", "LP", and "Vid." respectively. Moreover, "I" was used to designate informed views while "N" was used to designate naïve views.

RESULTS

All data sources were analyzed independently and then together in order to generate a profile for each teacher. The numerous and varied types of data sources (questionnaires, interviews, lesson plans, and observations) allowed for the triangulation of the data and thus, the construction of credible profiles for teachers.

Conceptions of NOS: VNOS-C and Interviews

Scientific Method(s). Most teachers (4: 57%) expressed the opinion that scientists use a specific method and a stepwise procedure, during their scientific investigations and defined an experiment as the manipulation of variables as illustrated in the following excerpts:

[Scientists'] use a specific method; there are steps, an ordered discipline. Everything is organized and deals with one thing at a time. (Teacher 4 [T4], Interview [Int.].)

[Scientists use one method] Problem, proposed explanation, testing the explanation, gathering data and conclusion. (T5, Int.)

The remaining teachers (3:43%) considered that scientists do not follow one method during their investigation which takes into consideration the subjectivity of the scientist's investigation as demonstrated in the excerpts below:

[There are] different methods that scientists can use, no standard one. (T6, Int.)

No one method, not the same process of testing or validating results could be other means of inquiry (T1, Int.).

Tentative NOS. When asked if a developed theory ever changes, all the participating teachers answered by yes. However, when asked about the reasons leading to the change of a scientific theory in the VNOS-C Questionnaire, teachers (7:100%) provided different explanations and justified their answers differently as illustrated in the following excerpts:

Theories change because new scientific knowledge doesn't always fit into the structure of a theory, so a theory must be modified in order to explain this new observation or accommodate this new knowledge (T1, VNOS)

Science may be subject to change when new evidence arises (T2, VNOS).

The explanation [theory] is not absolute but the most accepted at the time being, based on evidence. Theories do change, if a new phenomenon might contradict a certain accepted theory or a scientific theory unifies various phenomena and at the same time forms a guide to research more phenomena. (T5, VNOS).

In their justifications, teachers attributed the change of old theories or other constructs to the accumulation of new evidence and the collection of new types of data. Hence, some of them believed that change is due to the accumulation of new evidence leading scientist to discard previous theories and to generate new ones that are more plausible and that fit the new evidence obtained, while others asserted that it is by accretion.

Empirical NOS. When asked if the development of scientific knowledge requires controlled experiments, almost all the participants answered by 'no'. However, to understand their answers fully, they were asked during the interviews if astronomy and anatomy, in which no controlled scientific experiments are usually performed, are considered as "sciences". The participants could be divided into three categories based on their answers to these questions. The first category included 3 (43%) of the participants who answered that both fields of study are considered science and that science does not necessitate conducting controlled experiments but is "based on and/or derived from observations of the natural world" as maintained by (Schwartz et al., 2004, p.613).

> *Astronomy and anatomy are considered science and science by definition does not necessarily require controlled experiments (T1, Int.).*
>
> *Science does not require experiments but we need observations (T4, Int.).*

Teachers in the other two categories either considered that science necessarily requires controlled experiments or believed that scientists actually do experiments in anatomy and astronomy such as observing colors of stars and trying to estimate their temperature, as asserted by one participant).

> *The development of scientific knowledge requires [controlled] experiments, because experiments include the trial and error strategy, which helps in proving a specific scientific point (T3, VNOS).*
>
> *Yes, we do [controlled] experiments [in astronomy and anatomy], to know how things are functioning (T3, Int.).*

Hence, 57.1% (4) of the participants held naïve views about the empirical basis of scientific knowledge.

Subjective NOS. When asked about this aspect, most participants, (4:57%) seemed to hold informed views as shown in the excerpts below:

> *Preconceived ideas can affect the analysis to a certain extent, but it's ok if they [scientists] are biased because they are trying to prove what they think is true (T4, VNOS)*
>
> *It is important to learn theories because they would be the base of understanding certain things and they would be used in discarding an old theory. Using the knowledge of the old theory and proving how they are wrong today (T4, VNOS)*

Moreover, participants considered that personal subjectivity is unavoidable and that "Personal values, agendas, and prior experiences dictate what and how scientists conduct their work" (Schwartz, et al., 2004, p: 613).

> *Scientists might have the same set of data, and might probably analyze things similarly but each scientist thinks differently. The difference in the way of thinking will lead scientists (even people) to different conclusions. (T3, VNOS).*

During the interview, one teacher said:

> *Although all scientists may have access to and use the same set of data, but each scientist has his own mentality and way of thinking and relating evidences to history (T6, VNOS)*

The NOS aspect related to observation versus inference is also related to subjectivity thus, both are analyzed concurrently and their results are reported together. Data analysis showed that most participants (5:71.4%) expressed informed views consistent with the view developed by Lederman (1992) as shown below:

> *[Scientists came up with different conclusions regarding the extinction of dinosaurs] based on their own personal ways of analysis. Same data, different analyses, this is what causes the difference and leads to good science (T4, Int.).*
>
> *No, scientists have not seen an atom, [they came up with this elaborate structure] based on experiments conducted or assumptions (T7, Int.).*

Not enough evidence was found to support the view of the remaining participants (2:28.5%) who seemed to express no position regarding this aspect.

Creative and imaginative NOS. Almost all of the participants (6:85.7%) expressed informed views regarding the creative and imaginative aspects of science. Despite this, participants differed as to the stages during which creativity comes into play in science. Some of them thought that creativity plays a role in the construction of a hypothesis; others claimed that scientists use their imagination as they try to attribute specific explanations to certain observations. Still others considered that creativity comes into play at all the stages of scientific inquiry and the scientific endeavor. The excerpts below demonstrate the views expressed by a number of participants:

> *Scientists have to use their creativity and imagination at all stages of the scientific inquiry. The planning and design of experiments requires a lot of imagination so does the process of data collection, especially if the tools of data collection are not available. The analysis of these results, however, needs the highest level of creativity (T1, VNOS).*
>
> *Creativity and imagination are used in science. …when hypothesizing, a scientist should use his imagination and think unconventionally to find a logical explanation to a certain question and he should be creative in finding the means to prove his hypothesis (T4, VNOS).*

One participant considered that imagination as such does not play a role in scientific investigations and thus, expressed a naïve view:

> *Scientists do not use their imagination and creativity in performing experiments, because experiments reflect results (facts) in real life, and you cannot be creative or imagine things in life (T3, VNOS)*

Table 2. Categorization of Participants' Views of NOS in Response to the VNOS-C and the Interviews and the Relative Percentages of Informed (I) and Naïve (N) views of NOS

	Aspect of the Nature of Science									
Teacher	Tentative	Empirical	Subjective	Creative and Imaginative	Observation vs. inference	Socio-cultural	Laws and theories	Total		
1	I	I	N	I	U	I	N	57.1%I	28.5%N	14.2%U
2	I	N	N	I	I	N	N	42.8%I	57.1%N	
3	I	N	I	I	I	I	N	71.4%I	28.5%N	
4	I	N	I	N	I	I	N	57.1%I	42.8%N	
5	I	N	I	I	I	N	N	57.1%I	42.8%N	
6	I	N	I	I	U	N	N	42.8%I	42.8%N	14.2%U
7	I	N	N	I	I	N	N	42.8%I	57.1%N	
Total	100% I 0% N	85.7% N 14.3% I	57% I 43% N	85.7% I 14.2% N	71.4% I 0% N 28.5% U	57% N 43% I	100%N 0% I			

I: Informed
N: Naïve
U: undetermined (no enough evidence to support the view)

Socio-cultural Embeddedness of NOS. Among the participants, 4 (57%) suggested that science was "universal" thus expressing naïve views related to this aspect as illustrated in the following excerpts:

Science is universal because the same laws and theories are true in all societies and cultures (T2, VNOS).

Science is universal and it is not limited by any cultural or social values, it should be directed towards one thing which is finding answers to unknowns (T6, VNOS)

The rest of the participants (3:43%) held more informed views related to this aspect.

Yes, science is affected by social and cultural values. The way [scientists] deal with things is affected by the socio-cultural environment in which scientists live (T4, Int.).

Laws and Theories. All the participants (7:100%) considered that theories are subject to experimentation, whenever proven true and after the accumulation of scientific evidence, they become significant and they gain a higher status and thus, become laws which are, according to the participants, scientific facts that are proven to be true; a naïve view (Lederman, 1992):

A scientific theory is a scientific idea that will change to be a scientific law after many experiments that will prove it (T3, VNOS).

Some theories become laws if proven (T1, Int.).

Analysis of the responses to the open-ended questionnaire and the individual interviews showed that, in general, teachers' views of NOS were fluid and lacked coherence. Even though some of the teachers expressed informed views about a few aspects, almost all of them showed naïve views related to different aspects. Table 2 presents a summary of these results.

NOS in the Lesson Plans

Each participant presented a minimum of 2 lesson plans for the 2 sessions observed. This resulted in 14 lesson plans which were labeled by using the teacher number followed by a letter to indicate the lesson. Thus "T1 LPa represents Teacher 1 Lesson Plan A.

Analysis on the lesson plans showed that only one teacher presented a lesson plan that included a laboratory investigation. However, this laboratory session included pre-prepared slides of the observations students were supposed to collect and teacher demonstrations of experiments. Students were not involved in any hands-on or data collection activities. The demonstrations included:

- ✓ *Performing the iodine test on starch and the Fehling test on reducing sugars.*
- ✓ *Testing for the presence of starch in a green leaf, a yellow leaf, and a parti-colored leaf.*
- ✓ *Demonstrating how KOH and Ca (OH) 2 absorb carbon dioxide. (Teacher7, Lesson Plan b [T7, LPb]):*

The rest of the lesson plans consisted of summaries of the content to be introduced as well as the key objectives to be attained at the end of the chapter or session. The following is an excerpt from a lesson plan:

Start the lesson by reminding students of the concepts covered during last period and any related concept to this lesson. Ask: in the previous lessons we learned how crude sap reaches the leaves. Who can remind us of the pathway it follows briefly? Ask: for the plant to make its food or organic substances it needs substances other than water and minerals, what is the substance? Ask: how does CO2 reach the leaf? Etc… (T4, LP a)

Table 3. Implicit vs. Explicit Teaching of the Aspects of NOS from the Analysis of the Participants' Lesson Plans

Teacher	LP	Topic	Aspect of NOS covered: Implicitly	Aspect of NOS covered: Explicitly
1	A	The nervous message (action potential)	Empirical: Analysis of experimental setups and results + conclusions	None
	B	Response of a neuron	Analysis of experimental setups and results + conclusions	None
	C	Synaptic transmission	Analysis of experimental setups and results + conclusions	None
2	A	Synaptic transmission	Empirical: Experiments + explanation and conclusions	None
	B	Discovery of hormones	Experiments + explanation and conclusions	None
3	A	Discovery of hormones	Empirical: Experiments + explanation and conclusions	None
	B	Hormonal communication	Experiments + explanation and conclusions	None
	C	Structure and function of the thyroid	Experiments + explanation and conclusions	None
4	A	Stomatal structure	Empirical: Experiments and explanations and conclusions	None
	B	Role of stomata	Experiments and explanations then derivation of conclusions	None
5	A	Relationship between plants and fungi	Empirical: Experiments and explanations then conclusions	None
	B	Plant supply with raw material	Experiments and explanations then derivation of conclusions	None
6	A	Role of stomata	Empirical: Experimental setups, observations, analyses and conclusions	None
	B	The use of photosynthetic products	Experimental setups, observations, analyses and conclusions	None
7	A	Autotrophy and photosynthesis	Empirical: Conducting experiments in with observations and conclusions.	None
	B	Plant supply with raw material	Conducting experiments in the lab with observations and conclusions.	None
	C	The use of photosynthetic products	Conducting experiments with observations and conclusions. Students analyze tables, documents, and graphs related to the content and interpret results	None

Objectives: at the end of instruction, the student should be able to:

- ✓ *List the different stages of an action potential.*
- ✓ *Describe the ionic phenomena taking place during each of the stages of an action potential.*
- ✓ *State the law of "all or none".*
- ✓ *Explain the coding of the nervous message.*
- ✓ *List the different steps of synaptic transmission. (T1, LP a)*

Analysis of the lesson plans showed that teachers did not mention the aspects of NOS either explicitly or implicitly. They simply listed sets of experimental results from which students were expected to reach specific pre-determined conclusions through analysis and interpretation. The following excerpts from an introduction to a lesson illustrate this point:

> *The different experimental setups and results provided in the worksheet prepared by the teacher will be analyzed, and the teacher will guide the students to build their understanding of synaptic transmission (T1, LP c)*
>
> *Communication via blood: Read document and explain it step by step to allow students to come up with analysis. (Skills: students will develop analytical skills) and then assign for students to prepare the rest of the experiments (T3, LP a)*

Table 4. Implicit versus Explicit Teaching of the Aspects of Nature of Science from the Analysis of the Participants' Classroom videotapes

Teacher	Videotape	Topic	Aspect of NOS covered implicitly	Aspect of NOS covered explicitly
1	A	Nature of the nervous message (action potential)	Empirical (experiments with analysis and then derivation of a conclusion)	None
	B	Synaptic transmission	Empirical (experiments with analysis and then derivation of a conclusion)	None
2	A	Synaptic transmission	Empirical (experiments with analysis and then derivation of a conclusion)	None
	B	Discovery of hormones	Empirical (experiments with analysis and then derivation of a conclusion)	None
3	A	Discovery of hormones	Empirical (experiments with analysis and then derivation of a conclusion)	None
	B	Structure and function of the thyroid	Empirical (experiments with analysis and then derivation of a conclusion)	None
4	A	Stomatal structure	Empirical (experiments with analysis and then derivation of a conclusion)	None
	B	Role of stomata	Empirical (experiments with analysis and then derivation of a conclusion)	None
5	A	Relationship between plants and fungi	Empirical (experiments with analysis and then derivation of a conclusion)	None
	B	Plant supply with raw material	Empirical (experiments with analysis and then derivation of a conclusion)	None
6	A	Stomata structure and function	Empirical (experiments with analysis and then derivation of a conclusion)	None
	B	The use of photosynthetic products	Empirical (experiments with analysis and then derivation of a conclusion)	None
7	A	Autotrophy and photosynthesis	Empirical (experiments with analysis and then derivation of a conclusion)	Empirical (Planning an experimental setup through performing a project)
	B	Plant supply with raw material	Empirical (experiments with analysis and then derivation of a conclusion)	

In conclusion, the lesson plans included summaries of content chapters and guidelines for analyzing, interpreting, and explaining experimental results presented in tables, graphs, charts or the like and available in the textbook. These activities are typical of what is given in biology official exams in Lebanon and thus, may be the result of this rather than due to a conscious effort by teachers to introduce NOS to their students. It is worth noting that using the words "Analysis" and "Interpretation" in lesson plans does not necessarily mean that students were being trained on using higher level cognitive skills. In the context of Lebanon schools, these terms represent the "official" definitions used in scoring exam papers in public examinations and on which students are trained to increase their chances of succeeding in public examinations. Table 3 presents the implicit versus explicit instances for planning to teach the aspects of NOS identified in the lesson plans. The only aspect addressed is the empirical NOS.

Furthermore, slightly more than half of the teachers (4:57%) claimed that they actually teach the aspects of NOS in their classrooms. However, as is evident in the lesson plans; teachers introduced students to analysis, interpretation and derivation of conclusions from experimental setups presented in the book during lessons. All these fall under the implicit teaching of the empirical aspect of NOS. In addition to the evidence from the lesson plans, analysis of the videotapes showed no explicit teaching of the empirical NOS as illustrated in the following excerpts:

> *The idea is that we have been provided the experimental procedure and the result for each experiment and we're supposed to say what each experiment means and what can we deduce from each experiment. (T1, Vid, A).*
>
> *We are going to analyze document b. read it, try to understand it and analyze it (T6, Vid, B).*

NOS in the Videotaped Classes

Even in class, teachers did not mention the aspects of the NOS explicitly. All the instances of implicitly addressing the empirical NOS included the analysis, interpretation and explanation of experimental results presented in tables, graphs or the like. Students were always required to derive conclusions and were always reminded of the criteria to answer specific questions:

That's a deduction, first they asked us to analyze, and the first question is analyze so how will you do that? We have to use numbers. I would start with the Y axis, means I would start from here, the frequency of AP increases from 1 to 9 as the stimulating temperature increases from 40 to 55 ºC. (T1, Vid, A)

Table 4 provides a summary of all the instances during which the aspects of NOS were taught in the classrooms as identified from the videotapes. Since the only aspect addressed is that related to the empirical nature of science which was implicitly brought up through the analysis of experiments and the derivation of conclusions, it is the only aspect mentioned in this table.

Mediating Classroom Variables Derived from Videotaping

In order to determine common practices of the teachers, specific pre-determined classroom variables were identified and classified to elucidate potential practices which either enhance or impede the translation of teaches' knowledge into classroom practices. Moreover, these classroom variables, such as, presenting scientific knowledge as testable and unified, using higher level questions, probing or the use of rote memory/recall, all differentiate the behaviors of teachers in their respective classrooms (Lederman & Zeidler, 1987). In addition, these variables either facilitate or impede the introduction of the aspects of NOS in science classrooms.

The following excerpt is taken from the classroom videotape of Teacher 1. The teacher stresses empirical validation of subject matter which is classified as the 'testable' variable.

How does the CNS [Central nervous system] "know" the difference between a weak light and a strong light? In order to do this, let's consider the following experiment. In this experiment, a certain receptor, let's say the eye, is isolated and an oscilloscope is connected to the sensory neuron, and here we give stimulations, light intensities, light of different intensities/strengths and we obtain the following results (writes results in table) (T1, Vid, A).

Another excerpt, also obtained from Teacher 1, shows that this teacher emphasizes the interrelatedness between the scientific disciplines specifically physics and biology. This emphasis denotes the classroom variable 'unified'.

If you remember from last year physics, SV [is the vertical sensitivity which is the scale of volts per division along the y-axis] *and VB* [is the time base which is the scale of milliseconds per division along the x-axis]. *So where you had SV and VB you can change them, so the shape of the AP [Action Potential] doesn't always have to be like this… (T1, Vid, A).*

Alternatively, Teacher 2 presents an experiment on the board and then asks:

Who can analyze the experiment and give me the significance?

What do you expect the experiments done by Pavlov to be and that led to answering the question about how the pancreas would know that there is food in the small intestine? (T2, Vid, A).

This indicates that the teacher uses 'High level questions' (design an experiment, derive a conclusion, analyze, and draw out a hypothesis…) and then uses 'probing' in order to initiate student response. Conversely, other teachers ask frequent questions that are at the factual/ knowledge level (Rote memory/recall) and do not enhance higher level thinking. Example:

In which direction does the crude sap move in documents A and B? (T7, Vid, A).

When the light intensity is zero, [what do we mean by] light intensity is zero? (T1, Vid, A)

Who can define the phloem vessel? What are the phloem vessels? (T6, Vid, B)

A summary of all the variables are presented in Table 5. It should be noted however, that the presence of the variable does not assure that it enhances the overall classroom atmosphere for teaching the aspects of NOS. This, on the contrary depends on the nature as well as on the definition of the variable.

At the level of teacher's content-specific characteristics, factors such as "creativity", "developmental", "fallibility", "testable" and "unified" were identified. It should be noted that all of these can provide insights about the teachers' views regarding the various aspects of NOS. Data analysis showed that teachers in this study stressed the testable variable (7:100%) which is in high congruence with the empirical NOS that is frequently and implicitly addressed whether in the lesson plans or in practice. Moreover, none of the teachers emphasized the developmental NOS which relates to beliefs regarding the tentative NOS. Similarly, almost all teachers (6:85.7%) neglected the creative aspect of NOS which relates to the role of imagination in developing scientific laws and theories governing various phenomena in nature.

Table 5. Summary of the Categorization of each Participant Classroom Variables

	Teacher							
	1	2	3	4	5	6	7	
Classroom Variable								**Total**
General Instructional Approach								
Rote Memory/	P	P	P	P	P	P	P	100%P
Recall Lecturing	N	P	P	P	P	P	P	85.7%P 14.3%N
Frequent Questioning	P	P	P	N	P	N	N	57.1%P 42.8%N
Higher Level Questions	P	P	N	N	N	N	N	28.5%P 71.4%N
Fragmented	N	U	U	U	U	U	U	0%P 14.3%N 85.7%U
Problem Solving	P	P	N	N	N	N	N	28.5%P 71.4%N
Receptive	P	P	P	N	P	P	P	85.7%P 14.3%N
Probing	P	P	N	N	N	P	N	42.8%P 57.1%N
Humor	P	U	U	U	P	N	N	28.5%P 28.5%N 42.8%U
Content-Specific Characteristics								
Amoral	N	N	N	N		N	N	0%P 100%N
Creativity	N	N	N	N		N	P	14.3%P 85.7%N
Developmental	N	N	N	N		N	N	0%P 100%N
Fallibility	U	U	U	U		U	U	14.2%P 85.7%U
Testable	P	P	P	P		P	P	100%P 0%N
Unified	U	U	P	P		U	P	57.1%P 42.8%U

Positive (P): if the variable is presented in the classroom
Negative (N): if the variable is not presented
Undetermined (U): no enough evidence to support the determination of the variable

Constraints on Teaching NOS

During the interviews, when asked about the factors that either enhance or impede teaching the aspects of NOS, the teachers provided various factors some of which are related to the condensed program required by the Lebanese curriculum which does not leave room for introducing these aspects. Additionally, teachers claimed that the time required to teach the curriculum does not allow them to cover NOS. This stems from the fact that some teachers view the aspects of NOS as less significant than other concepts and hence, choose to devote less or even no time for presenting them in their classrooms. A number of the teachers also asserted that the school facilities and the experiences of the teachers play a major role in hindering the teaching of these aspects. For example, a number of the teachers said that they did not have enough knowledge about NOS and how to teach it even though they have been introduced to these aspects in their university classes. Additionally, some teachers said that school laboratories were not fully equipped and thus, were not sufficient for "doing science".

Another obstacle that teachers identified was the textbooks adopted by the school. According to these teachers, textbooks that are published by the Center for Educational Research and Development, (1994)

Table 6. Summary of the Factors and the Claims about Teaching or not Teaching NOS

Teacher	Claims about teaching aspects of NOS	Factors
1	I tried to teach it but it requires more work	• Program is condensed • Books dump the theory as it is, no description of the methodology • Students' backgrounds (consumers and not producers) • Hard to instill the theory or concept
2	No, I don't teach it.	• Students will become skeptic about any idea that they find weird (no trust)
3	I show the ideas. We present the ideas and we discuss them but in the end it is how the students believe and think	• Books are so limited • Assessment is more important, students don't know how to answer to specific questions • Concepts to be discussed are so limited. • Students' background. • Classroom management
4	Yes, I do teach it to make students act as scientists, be analytical, use their minds and accept new explanations. I mention that science changes.	• No factors hinder the presentation of these aspects
5	Yes, I do teach it. I stop the lesson and discuss many things. It is not scheduled, it is occasional. A question might provoke it.	• Time, schedule and syllabus do not allow for teaching NOS. We have to finish the curriculum on time. • Teachers' experiences: not all teachers have enough background knowledge to teach aspects of NOS • School facilities: no equipment to do experiments
6	No, I do not teach it.	• Limited curriculum: do not go beyond the concepts in the book. • Level of students is weak • Classroom management • Concepts
7	Definitely I teach it. Refer and try to observe things happening. Students do lots of experiments and they design their own using any kind of equipment to enhance their creativity.	• Requirement of the curriculum: Lebanese curriculum does not require experiments • The school system and the equipment.

(CERD) do not pay any attention to NOS. According to Teacher 1, textbooks

"…dump a theory the way it is, very few books describe the method by which the theory developed" (T1, Int.).

One of the teachers suggested that the cognitive level of the students also prevents teachers from introducing NOS in class especially that grade 10 students are of mixed abilities, many of whom are not interested in science. On the other hand, another teacher said that classroom management is a factor that prevented her from teaching NOS. Interestingly, one of the teachers believed that nothing prevented her from introducing NOS in her classroom and that she actually teaches these aspects. However, analysis of videotapes from her class indicated that this teacher does not actually do so. Even though teachers listed factors that hindered the teaching of the aspects of NOS, 4 of them (57%) claimed that they do present these aspects in their classrooms. A summary of the results are presented in Table 6.

Teacher Profiles

Results from the sections above were used to construct teacher profiles. Table 7 presents a summary of these profiles. By referring the Table 7, it becomes obvious that teachers' NOS conceptions have no direct impact on the practices, as an example, participants 1, 3, 4, and 5 had positive views of NOS but not sufficient to insure the teaching of NOS their classrooms.

Table 7. Summary of Participants' Profiles

Teacher	Views of the aspects of NOS	Lesson plans	Classroom practices	Profile
1	Positive 66.6% I 33.3% N	Analysis of experiments	Empirical Implicit	The knowledge of the aspects of NOS is positive however, classroom practice does not reflect these aspects.
2	Negative 28.5% I 71.4% N	Analysis of experiments	Empirical Implicit	The knowledge of the aspects of NOS is negative and teaching these aspects is not addressed in classrooms.
3	Positive 57% I 42.8% N	Analysis of experiments	Empirical Implicit	The knowledge of the aspects of NOS is positive however, classroom practice does not reflect these aspects.
4	Positive 71.4% I 28.5% N	Analysis of experiments	Empirical Implicit	The knowledge of the aspects of NOS is positive however, classroom practice does not reflect these aspects.
5	Positive 57% I 42.8% N	Analysis of experiments	Empirical Implicit	The knowledge of the aspects of NOS is positive however, classroom practice does not reflect these aspects.
6	Negative 33.3% I 66.6% N	Analysis of experiments	Empirical Implicit	The knowledge of the aspects of NOS is positive however, classroom practice does not reflect these aspects.
7	Negative 28.5% I 71.4% N	Analysis and conducting of experiments during the lab sessions	Empirical Implicit	The knowledge of the aspects of NOS is positive however, classroom practice does not reflect these aspects.

Positive views of the aspects of NOS (knowledge): 50% of the views are informed (I).
Negative views of the aspects of NOS (knowledge): 50% of the views are naïve (N).

CONCLUSION, DISCUSSION AND IMPLICATIONS

Current reform efforts in science education are consistently advocating the development of scientific literacy among students. The success of such a goal necessitates the preparation of knowledgeable teachers with appropriate NOS pedagogical content knowledge (NOS PCK) as suggested by Abd-El-Khalick and Lederman (2000a, 2000b) which not only comprises standard views and attitudes towards the aspects of NOS but in addition, instills in teachers the ability to introduce these to their students by using various pedagogical approaches. Based on the results of the study the following assertions can be made in response to the research questions (How do teachers' conceptions influence their practices about NOS? and what are the factors that mediate the relationship between conceptions and practice?)

***Assertion 1**: Participant teachers possessed incoherent and inconsistent views of the various aspects of NOS.* Almost all teachers expressed naïve views related to certain aspects of the nature of science such as empirical, creative and imaginative, and sociocultural embeddedness. In addition, they all thought that theories and laws are hierarchically related. On the contrary, all the teachers believed that science and scientific knowledge change with the emergence of new evidence. Moreover, almost all expressed the view that science is subjective, that is, it is influenced by current theories and by the scientist's own background, and that inferences are interpretations of observations which are made through human senses.

As indicated in Assertion 1, teachers' conceptions were found lacking and incoherent in many respects. Previous research in Lebanon (Abd-El-Khalick, 2001; BouJaoude, 1999, 2000; BouJaoude & Abd-El-Khalick, 1995; Farah, 1994) has reported similar findings related to these naïve and inconsistent views. These possibly originate from the type of education these teachers were exposed to whether in their high-school or college education. As proposed by Irez (2006), the educational history of a science teacher is an important contributing factor to his or her beliefs about NOS. Even though preparation programs might cover aspects of NOS, these programs are not long enough or sufficiently focused on teaching NOS to reverse the beliefs that teachers have developed in their long experience with science in school and at the college level during which the emphasis is typically on science as content and in assessment systems that measure the acquisition of this content to the neglect of the other aspects of the scientific endeavor.

As previously asserted, the results reveal that teachers' understandings of NOS were inconsistent and fragmented, as an example, a number of teachers who viewed science as tentative still believed that theories became laws that represented sure factual knowledge, a finding that resonates with research results reported by Schwartz, Lederman, and Crawford (2004). These results suggest that teacher education programs do not emphasize NOS aspects sufficiently or that teachers themselves do not take this matter seriously, an issue that has not been adequately researched in Lebanon. Educational institutions are bound to modify the structure as well as the content of teacher preparation programs as recommended by BouJaoude (2000). BouJaoude also stresses the fact that teachers are not well prepared during their pre-service training to become decision-makers and reflective problem solvers. Such insufficient preparation results in the replication of the modes of teaching to which teachers themselves were exposed to, leading to teachers who prepare students possessing a large store of knowledge about science but are not capable of reflecting their knowledge in everyday life while attempting to solve personal and societal problems.

Assertion 2: *Whether naïve or informed, the NOS aspects were neither planned for nor taught in the classrooms, except for implicit instances for teaching the empirical NOS*. When asked about the reasons, the participating teachers listed a number of factors which included the curriculum, textbooks, students' backgrounds, lack of time, classroom management, as well as the assessment criteria and practices.

The results of this study clearly show that teachers' NOS conceptions have no direct impact on classroom practice and that an aggregate of various factors coalesce to determine this practice and shape the overall atmosphere of the classroom and of the instructional practices adopted by a specific teacher in a specific context. Previous research has paid significant attention to teachers' understanding of NOS (Abd-El-Khalick & Lederman, 2000a; Bell, Lederman, & Abd-El-Khalick, 2000; Lederman, 1995; Schwarz & Lederman, 2002, Aslan & Taşar, 2013). The results of this study suggest that this is only one factor among other critical ones that need to be considered in order to understand why high school students do not possess adequate understanding of NOS. Whilst classroom practices are not necessarily a direct consequence of possessing appropriate NOS conceptions, teachers participating in this study neither planned for nor addressed aspects of NOS, at least those aspects for which they held informed views, in their classrooms. This suggests that various factors coalesce to determine the translation of knowledge into actual practice. Among these, as implied by the results of this study, and as suggested by the participating teachers, are problems with classroom management, the Lebanese curriculum and its textbooks, as well as the summative public assessment practices adopted as promotion criteria. Additionally, teachers might possess adequate NOS understanding, but do not have the necessary tools to teach these conceptions such as activities and appropriate resources. Teachers participating in this study paid minimal attention to any of the NOS aspects. Even when the empirical NOS was implicitly addressed, these teachers did not intend to address it. This aspect was part of their lessons. Teachers emphasized supporting evidence since they needed it to help students derive conclusions and perform the necessary analysis of various scientific documents presented in the textbooks; skills that students need to answer questions on public national examinations. Since NOS aspects are not part of public examinations and require a lot of work, as asserted by one of the study participants during the interview, teachers do not plan to address those aspects in their science classrooms. Furthermore, another participant in this study claimed that introducing students to these aspects might cause them to become skeptical about science and scientific knowledge in general and thus, was not ready to emphasize it. The above arguments seem to stem from teachers' views about the necessity and value of NOS understanding; which might influence their intentions to teach NOS.

Assertion 3: *Analyzing the videotapes showed that the participant teachers emphasized rote memorizing/recall, almost all used lecturing with minimal student involvement as the main instructional technique, and rarely used problem solving, open ended questions or discrepant events.* This is not in congruence with the aspects of the nature of science and more importantly, this does not correspond to an appropriate teaching of these aspects. In addition, the analysis showed that teachers stressed the testable nature of scientific knowledge, that is, the empirical NOS but neglected the tentativeness of scientific knowledge and the creative NOS which relates to the role of imagination in developing scientific laws and theories. This will possibly impede the development of citizens who aim at developing science and not merely consuming science and scientific advancements. Since classroom variables can provide insights about the teachers' views regarding the various aspects of NOS, it was apparent that the factors identified above established a classroom environment that was not conducive to the introduction of the aspects of NOS and thus, impeded the translation of teachers' knowledge, if it existed, into actual classroom practices.

Implications for Teaching and Research

The findings of this study suggest that effective teaching of the aspects of NOS requires change at the school and the educational system level. First, there is a need to prepare in-service as well as pre-service teachers to teach the aspects of NOS. As mentioned above these teachers need to understand and posses the skills to teach NOS. This change however, will not happen unless the curriculum, textbooks, and assessment practices change in such a way as to value teaching NOS. As suggested by Lederman (2006), the goals of teaching NOS should be considered a cognitive rather than an affective outcome, a consideration that necessitates teaching NOS aspects explicitly rather that assuming that students will acquire these conceptions implicitly during teaching.

Gaining insights about the origin of teachers' NOS conceptions might provide insights regarding the reasons for neglecting of the aspects of NOS in teaching. In addition, investigating the effect of teachers' practices, beliefs and conceptions on students' views about science in general and scientific knowledge more specifically, is essential for understanding ways by which these beliefs and practices could be changed to benefit students. Similarly, investigating implicit versus explicit teaching of different aspects of NOS is important to understand how NOS can be taught in ways that makes it meaningful for students. Finally, the classroom is a complex entity and it should be treated as such, the conditions necessary for good teaching are varied and complex. Thus, isolating one or more factors to study might not be productive. There is a need to design research studies that mirror classroom complexity. This could be done by conducting long term research studies that employ multiple research methods and that address a variety of issues concurrently.

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APPENDIX I

Interview Protocol

Name: ______________________

School: _____________________

Interview protocol developed by Abd-El-Khalick et. al (2001)

1. Do all scientists use a specific method, in terms of a certain stepwise procedure, when they do science? Can you elaborate?
2. Are you thinking of an experiment in the sense of manipulating variables or are you thinking of more general procedures? Can you elaborate?
3. "Let's consider a science like astronomy (or anatomy). Can we (or do we) do manipulative experiments in astronomy (or anatomy)?"
   - If the answer is positive, the interviewees are asked to explicate their answers and to provide examples.
   - If the answer is negative, the interviewees are then asked, "But we still consider astronomy (or anatomy) a science. What are your ideas about that?"
4. When scientists perform 'manipulative' experiments they hold certain variables and constant and vary others. Do scientists usually have an idea about the outcome of their experiments?"
   - If agreement is established then they were asked, "Some claim that such expectations would bias the results of an experiment. What do you think?"
5. The history of science is full of examples of scientific theories that have been discarded or greatly changed. The life spans of scientific theories, if you will, vary greatly, but theories seem to change at one point or another. And there is no reason to believe that the scientific theories we have today will not change in the future. Why do we bother learn about these theories? Why do we invest time and energy to grasp these theories?
6. Which comes first when scientists conduct scientific investigations theory or observation?
7. In terms of status and significance as products of science, would you rank scientific theories and laws? And if you choose to rank them, how would you rank them?
8. Have we ever 'seen' an atom?
   - If the answer is negative, a new question is then posed: "So, where do scientists come up with this elaborate structure of the atom?"
   - If the answer is positive then the interviewees are asked to elaborate. On their answers.
9. There are certain species of wolfs and dogs that are known to interbreed and produce fertile offspring. How does this fit into the notion of specie, knowing that the aforementioned species are 'different' species and have different names?
10. Creativity and imagination also have the connotation of creating something from the mind. Do you think creativity and imagination play a part in science in that sense as well?
11. In your classroom, do you instill the aspects of NOS among your students?
    - If the answer is yes, the participants are asked to elaborate on their answers.
    - If the answer is no, the participants are asked about the possible reasons that hinder them from instilling these aspects in their students' minds.