Investigating the relationship between teachers' nature of science conceptions and their practice of inquiry science

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Abstract

In addition to recommending inquiry as the primary approach to teaching science, developers of recent reform efforts in science education have also strongly suggested that teachers develop a sound understanding of the nature of science.

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Most studies on teachers' NOS conceptions and inquiry beliefs investigated these concepts of teachers' NOS conceptions and inquiry beliefs and practices as separate phenomena rather than understanding how one influences the other. A few studies (e.g. Akerson, Abd-El-Khalick, & Lederman 2000; Bencze, Bowen, & Alsop, 2006; Keys & Bryan, 2000; Lotter et al, 2007; Tsai 2002) implies a relationship between science teachers' NOS conceptions and their practices and beliefs about inquiry, which necessitates further research on the relationship (Eick, 2000; Tsai, 2002).The purpose of this study is to understand how science teachers' NOS conceptions relate to their beliefs about inquiry and influence their inquiry science practices in the classroom as revealed through online learning. The participants of this study are practicing teachers who were accepted into an online science education Masters Program. Findings suggest that the teachers who possess more sophisticated understanding of NOS implement less structured inquiries. A better understanding of NOS conceptions assists the teachers in developing a higher appreciation of inquiry science instruction. It further enables them to realize how NOS concepts, inquiry science instruction, and the goal of creating a scientifically literate society fit all together.

Keywords: Inquiry science, Nature of Science, teacher beliefs

Introduction

Inquiry-based science has been the major theme of many national projects and has been used as a rationale for nationwide reform efforts in middle and secondary science education across the U.S. (e.g., AAAS, 1993; NRC, 1996, 2000; PSSC, 1956). National documents written by the proponents of the most recent reform efforts are increasingly recommending that science teachers use inquiry as the primary approach to teaching science (NRC, 1996; NSTA, 2003).

In addition to recommending inquiry as the primary approach to teaching science, developers of recent reform efforts in science education have also strongly suggested that teachers develop a sound understanding of the nature of science (NOS) (NRC 1996; NSTA, 2003). An understanding of NOS is necessary because it has been found that the actions of teachers are influenced by their perceptions of science as an enterprise and as a subject to be taught and learned. (Lederman, 2007; Ochanji, 2003). Similarly, teachers' approaches to teaching science are influenced

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by their NOS conceptions (Bencze, et al., 2006; Karakas, 20009; Lotter, Harwood, & Bonner 2007; Southerland, Gess-Newsome, & Johnston, 2003; Tsai, 2002). However, the relationship between teachers' NOS conceptions and their classroom practices is complicated and far from being linear (Akerson, Cullen, & Hanson, 2009; Southerland et al. 2003).

Inquiry Teaching

Although inquiry based science instruction is a key element of many reform efforts in the U.S, it is yet not perfectly clear what is meant by inquiry teaching and how successful inquiry teaching can be performed in K12 classrooms (Anderson, 2002). One of the main recommendations of many national reports (AAAS, 1993; NRC 2000) is to educate teachers to teach science as inquiry. It is especially important to understand what inquiry teaching means for practicing teachers, as they are the key players in successfully implementing science education reform.

In an attempt to define and describe inquiry science teaching, Edelson (1998) claims that in the simplest way, inquiry science teaching refers to the adaptation of science practice for classrooms. Science teaching through inquiry requires both the knowledge of content and methods, (Hart, 2002) and/or knowledge of subject matter and knowledge of pedagogy (Tobin, Tippins & Gallard, 1994). Inquiry teaching refers to a way of thinking (Schwab, 1964) that helps science teachers become more creative in designing and implementing science curricula.

Nature of Science (NOS)

In science education literature, NOS is used as an inclusive phrase to describe "scientific enterprise for science education" (McComas, Clough, & Almazroa, 1998, p. 4). Prior to the usage of NOS, scientific enterprise and relationship between scientific disciplines were studied as part of history and philosophy of science (McComas et al, 1998). Many educators use NOS "to describe the intersection of issues addressed by the philosophy, history, sociology, and psychology of science as they apply to and potentially impact science teaching and learning" (McComas et al, 1998, p. 5).

Typically, NOS refers to values and beliefs inherent to the development of scientific knowledge (Lederman, 1992). NOS also represents the value system embedded in scientific knowledge (Lederman, 1992; Abd-El-Khalick et al., 1998).

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Typical NOS studies seek an individual's answers at least on the following five questions: (1) What is Science?; (2) How is science pursued?; (3)What is the nature of scientific knowledge?; (4) What are the values embedded in scientific knowledge?; and, (5) Who is a scientist?

Although the above questions seem to be simple and straightforward, answers to these questions can be quite diverse and complicated. Unfortunately, many Americans' answers to the above questions are contaminated with misconceptions and, thus, do not represent the true nature of science or scientific knowledge (McComas, 1998).

How NOS Conceptions Relates to Teachers' Inquiry Science Instruction

Specifically, in regard to the relationship between teachers' NOS conceptions and their use of inquiry in their classroom, science education literature suggests that teachers' NOS conceptions directly or indirectly influence their inquiry science instruction in a number of ways. First, Moscovici (1999) argues that science teachers' views about NOS greatly influence their ability and willingness to bring inquiry science to the classroom. Unfortunately, not many teachers hold desired understandings of NOS (Abd-El-Khalick, & Lederman, 2000; Lederman, 1992; Pomeroy, 1993; Ryan & Aikenhead, 1992). However, teachers' conceptions of the NOS are dynamic and open to change (Akerson & Hanuscin, 2007; Lederman, et al., 2002).

Second, teachers' conception of NOS may also influence the type and quality of inquiry science instruction that takes place in science classrooms (Bencze, Bowen, & Alsop, 2006; Keys & Brian, 2001; Lotter et al., 2007; Roehrig & Luft, 2004; Trumbull, Scarano, & Bonney 2006; Tsai, 2002). In the following excerpt Yerrick, Parke, and Nugent (1997) highlights the influence of teachers' NOS conceptions on their classroom practices:

Teachers who believe knowledge is a group of facts to be delivered to the student will simply concern themselves with the transmission of a completed package. In contrast, teachers who are concerned with the students' interpretations of this knowledge will be interested in seeing how the knowledge is transformed by the students' attempts to use the newly acquired knowledge. (p. 139)

In support of the above argument, Keys & Bryan (2001) found that teachers who hold the desired view of NOS are more likely to implement problem-based science

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instruction. Also, Trumbull et al., (2006) found that the teacher who held proximal view of NOS conceptions implemented more student led investigations than the teacher who held a distal view of NOS conceptions. Similarly, Lotter et al. (2007) found that teachers' conceptions of science guided the teachers' use of inquiry-based practices. Also, Bencze et al.,(2006), found that teachers' use of inquiry practices in the classroom were reflective of their NOS conceptions.

Statement of the Problem

A literature review reveals that most studies on teachers' NOS conceptions and inquiry beliefs investigated these concepts of teachers' NOS conceptions and inquiry beliefs and practices as separate phenomena rather than understanding how one influences the other in detail. However, studies in the literature indicate that science teachers' NOS conceptions and inquiry beliefs and practices are not separate entities and that they influence one another (Abd-El-Khalick, Boujaoude, Dushl, Lederman, Hofstein, Niaz, Tregust, &Tuan, 2004; Eick, 2000; Keys & Bryan, 2000; Lotter, et al., 2007; Moscovici, 1998; Tsai, 2002). Furthermore, Akerson et al. (2000) indicate that NOS views are byproducts of the inquiry process. Several studies (e.g. Bencze, Bowen, & Alsop, 2006; Keys & Bryan, 2000; Lotter et al, 2007; Moscovici, 1998; 1999; Schwartz, Lederman, & Crawford, 2004; Tsai 2002) address the relationship between teachers' NOS conceptions and inquiry beliefs. In some of these studies the relationship between teachers' NOS conceptions and inquiry science beliefs and practices either implicitly mentioned or was not explored in depth, which necessitates further research on the relationship (Eick, 2000; Moscovici, 1998; Tsai, 2002). As an example, concerning the relationship between science teachers' NOS conceptions and inquiry beliefs, earlier studies indicate that inquiry science experience helps teachers understand the NOS and the NOS instruction (Akerson & Hanuscin, 2007; Lotter et al., 2007; Rosenthal, 1993).

Also, research on the relationship between teachers' NOS conceptions and their classroom practices report conflicting results. On one hand, it has been documented in science education literature that the actions of teachers are influenced by their perceptions of science as an enterprise and as a subject to be taught and learned (Lotter et al., 2007; Roehrig & Luft, 2004). Similarly, many studies report that the design and implementation of science lessons reflect teachers' NOS conceptions

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(Lotter, et al., 2007; Matson & Parsons, 1998; Southerland, et al., 2003; Rosenthal, 1993; Turner & Sullenger, 1998; Tsai, 2002).

On the other hand, there are studies in science education literature that suggests that teachers' NOS conceptions do not necessarily influence their classroom practices (Abd-El Khalick et al., 1998; Duschl & Wright, 1989; Hipkins, Barker, & Bolstad 2005; Karakas, 2009; Lederman, 1999; Lederman & Zeidler, 1987). More research is needed to further establish the relationship between teachers' NOS conceptions and their inquiry beliefs and practices in the classroom.

Purpose of the Study

The purpose of this study is to understand how science teachers' NOS conceptions relate to their beliefs about inquiry and influence their inquiry science practices in the classroom as revealed through online learning. The research questions that guided this study are:

1. How do teachers' NOS conceptions influence their inquiry science practices in the classroom?
2. How does a change in the sophistication level of teachers' NOS concepts influence their inquiry science practices in the classroom?

Methods

This study used the naturalistic paradigm to investigate the relationship between teachers' NOS conceptions and their inquiry science practices because naturalistic paradigm provides the best fit when the purpose is to get at the meaning as constructed by the participants (Guba & Lincoln, 1989).

Research Context and Participants

The participants of this study are practicing teachers who were accepted into an online science education Master's program at a southern university. This Master's program is specifically designed for practicing science teachers who are certified. One of the logistical aspects of this program is to reach out to practicing teachers who are unable to attend college courses for a variety of reasons to include time and distance. The main purpose of the Master's Program is to help teachers

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improve their science teaching methods, research abilities, pedagogy, and philosophy of science teaching in their classroom. Three online courses constituted the research setting of this study: (1) Special Problems in the Teaching of Secondary School Science: Nature of Science & Science Teaching (NOSST), (2) Curriculum in Science Education (CSE), and (3) Colloquium (COL). The purpose of the NOSST course was to enhance teachers' understanding of NOS conceptions. Whereas the main purpose of CSE course was to enhance teachers' understanding of inquiry science by engaging them in inquiry science activities and providing them a context to reflect on their experiences. Finally, the purpose of the COL course was to provide a context for teachers further discuss the issues that are related to NOS and implementation of inquiry science in middle school settings.

At the beginning of the semester, all of the 14 teachers enrolled in the NOS course were administered the VNOS-C questionnaire by the course instructor in order to get their views about the NOS. After the respondents completed the questionnaires, each participant's NOS responses were analyzed by comparing and contrasting each teacher's responses with the desired NOS conceptions mentioned in McComas (1998). In addition, the teachers' electronic postings in the NOS course were analyzed. As a result, the teachers' responses were holistically categorized into three groups as those who hold: (1) simplistic, (2) sophisticated, and (3) in-between NOS conceptions. The initial plan was to purposefully select (Guba & Lincoln, 1989) two teachers from each category. None of the teachers held sophisticated understanding in all aspects of the VNOS questionnaire. Therefore, four teachers who thought to be the best informants (Guba & Lincoln, 1989) were selected as focus group teachers. Through the middle of the research, one of the teachers asked to be excluded from the research due to her overwhelming course and work schedule. The teachers' agreement were sought to participate in the research by having them sign a letter of consent. Pseudonyms are used to protect the teachers' confidentiality.

Data Sources

Multiple data sources were used for data triangulation (Miles & Huberman, 1984) in order to understand the relationship between participants' NOS views and their conceptions and beliefs about inquiry-based science teaching. These include: (1) VNOS-C questionnaire, (2) Electronic postings in all three online courses, (3)

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Semi-structured interviews, (4) email correspondence, and (5) Samples of inquiry teaching videos and lesson plans.

VNOS-C Questionnaire

The VNOS-C questionnaire (STILT, 2004), contains ten open-ended questions about teachers' NOS conceptions. Each question deals with a different aspect of science. All teachers enrolled in the NOS course were to take the VNOS-C questionnaire as part of fulfilling the requirements of the course. Once the questionnaire was completed, each participant's VNOS-C responses were summarized (Abd-El-Khalick, Lederman, Bell, & Schwartz, 2001). Then a comparison and contrasting of each teacher's responses with the desired NOS conceptions (simplistic, sophisticated and in-between) mentioned in McComas (1998) was made.

Electronic Postings

Electronic postings were composed of reflections and responses of teachers that were posted in discussion boards in the Blackboard system throughout the semester. These discussion board topics included but were not limited to: (1) Weekly critical reviews of assigned readings, (2) Other participants' responses to teachers' critical reviews, (3) Teachers' responses to weekly prompts assigned by the instructor and (4) Weekly peer assessments. The length of the teachers' reflections and responses ranged from a couple sentences to three pages. All of these electronic interactions were archived in the Blackboard system.

Semi-Structured Interviews

Interviews are particularly useful while investigating issues in a more in-depth-way, (Guba & Lincoln, 1989) as they often reveal detailed information on the perceptions, intentions, thoughts, and beliefs of participants (Guba & Lincoln, 1989; Fontana & Frey, 2000).

In this research, the interviews were conducted in a semi-structured format allowing the researcher to be flexible in following up the given responses. The questions during semi-structured interviews focused on the following themes: (1) Participants' descriptions of inquiry learning and inquiry-based science teaching; (2) Participants' experiences with inquiry science instruction ; (3) Participants' perceptions of advantages and disadvantages of inquiry learning and inquiry-based

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teaching; (4)Participants' NOS conceptions; and (5) The influence of the NOS and inquiry online courses on participants' classroom practices. Each teacher was interviewed twice. The length of the interviews ranged from approximately two hours to two and a half hours.

Videotapes

For the purpose of the Curriculum and NOS courses, teachers were to videotape at least one class period of their inquiry teaching and mail it to one of the course instructors. The lengths of the videotapes were approximately two hours, an hour, and an hour for Kelly, Amy, and Jason, respectively. Videotapes were analyzed in order to gain an understanding about how teachers utilized inquiry-based teaching methods while teaching scientific concepts.

Each teacher's inquiry class was categorized in one of the three categories of open, guided and structured inquiry using an Inquiry Scoring Rubric(ISR) developed by the author. Each category consisted of eight variables. According to the Inquiry Rubric, for instance, "Open Inquiry" teaching involved the following characteristics: (1) Student questions give direction to the lesson; (2) The teacher strongly encourages student thinking and reasoning; (3) The teacher never provides the correct answer; (4) Student participation is strongly encouraged; (5) Students hypothesize, make predictions and design their own investigations to test own hypothesis; (6) Students deeply engage in data analysis; (7) Students exchange ideas among each other and with the teacher; and, (8) Investigations may extend over a long period of time.

Data Analysis

Data collection and data analysis were conducted simultaneously in this research. Simultaneous data analysis in qualitative studies has several advantages over the analysis that takes place after all data is collected. First, as Miles & Huberman (1984, p.49) argue, reflecting on the newly collected data in small chunks rather than in big bulk enables the researcher to generate new questions and give new direction to the study. It further enables the researcher to collect "better quality" data as the researcher gains better insight into the study s/he is conducting.

Using constant comparative method (Strauss & Corbin, 1998), data was reorganized by identifying several patterns, categories, and themes. Throughout the

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data analysis procedure, comparisons and contrasts were made (Miles & Huberman, 1984) between different data sources. Data was analyzed many times always looking for relationships and themes to emerge. Some of the themes that emerged from the study were influence of teachers' NOS conceptions on their confidence and intentions of using inquiry in their classrooms,. The themes and assertions were verified by further data collection and analysis. Finally, interpretations and assertions were made as a result of the analysis of each data source that was confirmed, combined with other assertions, or unconfirmed. The final outcome of this study was reported as a set of assertions supported through the triangulation of the various data sources.

Validity

The researchers attempted to enhance information richness by providing thick description of the research context. The purpose of thick description is "to facilitate the transferability of judgments on the parts of others who may wish to apply the study to their own situations" (Guba & Lincoln, 1989, p. 242). The validity of themes and assertions was enhanced through triangulation with interviews, electronic postings, VNOS questionnaire responses and teaching videos.

The researchers sought focus group teachers' approval of the interpretations before putting them in the final draft. During this member checking process, the focus group teachers were sent the final draft along with a letter that encouraged teachers to add, delete or comment on the interpretations made in the final draft. . The focus group teachers did not have any revisions on the final draft and as requested sent a signed letter back to the researcher that indicated their approval of the researcher's interpretations.

In order to further enhance the validity the interpretations the researcher employed peer debriefing technique (Guba & Lincoln, 1989). The researcher and several other doctoral students met on a weekly basis to discuss their research findings and analysis of data. During these meetings the researcher shared the categories and themes that emerged from the data and asked his colleagues to provide feedback on the soundness of the categories, themes and his interpretations. The researcher also met with his major professor (the second author) to discuss the findings of the research more in depth.

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Results

The Teachers' Understandings of NOS Concepts

Analysis of the teachers' VNOS responses and their electronic postings in the NOS course indicate that none of the teachers' holds a sophisticated understanding in all of the VNOS prompts. Some of teachers' responses to an individual prompt reflect both a sophisticated and a naïve understanding of NOS concepts. Among the three teachers, Kelly' is the only teacher whose NOS conceptions are holistically categorized as naïve, whereas Amy's and Jason's NOS conceptions are categorized as in-between category. I present examples of the teachers' sophisticated and naive NOS conceptions in the following paragraphs.

Kelly holds the least sophisticated understanding of NOS concepts introduced in the VNOS questionnaire. Although she holds a sophisticated and in-between understanding of some aspects of NOS, the majority of her NOS conceptions as stated in the VNOS questionnaire fell in the category of "naïve" NOS conceptions. As an example to her undesired NOS conception, she states, "A scientific law is proven and occurs repeatedly. It can be thought of as a universal truth" (Kelly, VNOS Questionnaire). Kelly's statements about scientific theories and laws suggest that her understanding of scientific theories and laws are not parallel to the desired NOS conceptions at least in two respects. First, labeling a scientific law as "proven" and "universal truth" suggests that scientific theories and laws are not equal in importance, but rather that scientific laws are, in fact, more important than scientific theories.

As the majority of Kelly's responses consisted of undesired NOS conceptions, we categorize her NOS conceptions to be somewhere in the "naïve" NOS concepts range. Kelly has the least adequate understanding of NOS conceptions, probably due to her limited science background. Kelly is an elementary school teacher and has limited experience with science.

Amy's VNOS responses appear to be more sophisticated than Kelly's. Amy's VNOS responses are categorized somewhere between "naïve" and "in-between", but closer to the in-between category. It appears that Amy's VNOS responses are composed of a balanced mixture of naïve, in-between, and sophisticated NOS conceptions. As an example to desired NOS conceptions Amy states:

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Experiments are required when possible; however, it is sometimes impossible to actually conduct an experiment because of lack of technology or distance, etc. Galileo's study of planetary movement is an example of scientific observation leading to a correct scientific conclusion. He made thorough, constant observations of the planets and carefully recorded his observations. Because of his observations and brilliance he was able to correctly predict planetary movement and deduct that we did not live in a geocentric universe. (Amy, VNOS Questionnaire)

Among the three focus group teachers, Amy provides the most adequate definition of what an experiment is. Amy defines an experiment as a "controlled test of one variable compared to a known factor" (Amy, VNOS Questionnaire). None of the other two teachers mention controlling for a variable. Amy also has a sophisticated understanding about the development of scientific knowledge.

As an example to desired NOS conceptions Jason believes that theories are as valid as laws. He states, "Evolution happens; it is as real and concrete as the Newtonian laws of motion" (Jason, VNOS Questionnaire). Also, Jason's understanding of scientific theories and laws appears to be sophisticated. Jason believes that scientific theories and laws are subject to change over time, "as we discover more" (Jason, VNOS Questionnaire). An analysis reveals that his understanding of NOS concepts fit somewhere between the "in-between" and "sophisticated" categories.

Assertion 1: Understanding NOS concepts more in depth helps the teachers to develop a higher appreciation of the importance of inquiry science instruction and boosts their confidence in teaching science through inquiry.

Kelly. Understanding NOS concepts more in-depth allows Kelly to develop a higher appreciation of the importance of inquiry science instruction. Better understanding of NOS concepts helps her see the mismatch between the real science and the science she has been practicing in her classroom. Seeing this mismatch provides a rationale for her as to why she should teach science through inquiry.

Better understanding of NOS conceptions enables Kelly to realize how NOS concepts, inquiry science instruction, and the goal of creating a scientifically literate society fit all together. She feels that the NOS course has helped her gain a new perspective of science. In order to translate her new perspective into her

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instruction, she feels that she has to integrate more inquiry approaches into her classroom:

Now that I have a different outlook on the nature of science, I feel like I was looking at the little pieces before and now I need to step back and focus on the whole picture. I need to really make inquiry-based learning my mantra. So I think my objectives need some more reflecting (Kelly, NOS, Discussion Board).

It is noteworthy in the above excerpt that a better understanding of NOS concepts triggers her to re-examine her entire approach to teaching science. She thinks that in order to initiate this change, she first has to start by revising her instructional objectives.

Amy. Better understanding the NOS concepts boosts Amy's confidence in her ability to integrate inquiry science into her instruction. Amy:

I realized I was more confident this year. I was wondering why. I truly think that NOS course did give me a lot more confidence just because it just nailed down so many things that perhaps were not 100% firm (Amy, Interview 2, September 29, 2005).

Developing a more sophisticated understanding of NOS helps Amy to overcome some of her misconceptions about inquiry learning. Better understanding of NOS concepts helps her realize that doing inquiry in the classroom does not necessarily mean doing hands-on activities all the time in the classroom. She states:

Inquiry does not hold you down to just exploring with some hands on activities, you can explore with some books or references, observations or whatever. I think that is very important. It does not hold you to one thing. (Amy, Interview 2, September 29, 2005)

As seen in the above excerpt, developing a more sophisticated understanding of NOS helps Amy to overcome some of her misconceptions about inquiry learning.

Jason. Jason states that a better understanding of NOS concepts alone does not make him to transform his traditional science instruction to inquiry science instruction but, rather, "gave him a different framework" (Jason, Interview 1, September 16, 2005) in making the change. It appears that a better understanding of

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NOS concepts contributes to his efforts of transforming his traditional classroom into an inquiry classroom by enhancing his ability to distinguish between the fake and real view of science more clearly. A better understanding of NOS concepts enables him to see how the different aspects and pieces of how science really works and fit together. He states:

Prior to joining the program I did understand that science was tentative, that science is culturally biased, that difference between inference and observation and all the wonderful NOS stuff. I did understand these points individually but I did not see them as an integrated whole. That came with taking the NOS class last semester. (Jason, Interview 1, September 16, 2005)

	Kelly	Amy	Jason
Better Understanding of NOS concepts	Helped her to see the mismatch between real science and the science she has been practicing	Boosts her confidence in integrating inquiry science into her instruction.	Gave him different framework to transform his traditional science classroom into inquiry science classroom
	Allows her to realize the connection between NOS, inquiry, and creating scientifically literate citizens	Allows her to realize inquiry science is not all about doing hands-on science	Enhances his ability to distinguish between fake and real science
	Encourages her to re-examine her approach to teaching science	Encourages her to put more emphasis on some aspects of inquiry more than others.	Enables him to see how the different aspects and pieces of how science really fit together

Table 1. Summary of the differences and similarities between the teachers involved in this study in regard to the influence of NOS conceptions on their practice of inquiry science.

Assertion 2: Sophistication of the teachers' NOS concepts influences their decisions about the type of inquiry they plan to incorporate in their instruction. The teachers

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who hold more sophisticated understanding of NOS conceptions intend to conduct inquiries that are less structured in nature.

Kelly. Kelly, as a student, learned best through collaboration. She states:

As I said earlier I work best with others. I hate open inquiry where I am just out there on my own. I find it very uncomfortable and a waste of time. I need some direction and scaffolding. I still think the support that is given during that stage is most critical if the learner is to be successful. This is such a tricky balance (KellyColloquium,prompt7).

It is clearly stated in the above excerpt that Kelly hates open inquiries as a student and holds the misconception that open inquiries have to be pursued alone. It is likely that she will not want to spend time on an open inquiry approach because she highly values collaboration in her classroom. She goes on even further to state: "I am just not convinced that the discovery should be left up to the students" (Kelly, Colloquium prompt 15). This, in a sense, is a confirmation of her opinion that she is neither ready nor willing to use open inquiry in her classroom.

Kelly also does not think that her students are ready for inquiry learning and can discover for themselves. Her lack of faith in students' ability to discover scientific knowledge for themselves may be tied to Kelly's beliefs about the role of creativity in the development of scientific knowledge. She states:

I think the aspect that involves invention of explanation is the most difficult for me. I am astounded by the creativeness that is involved in science. I also struggle with the tentativeness of science. Sometimes I think the more I learn the less I know. This kind of falls back to my religious background- what an awesome world we live in and who can be so bold as to try to explain all of its workings (Kelly, NOS, Personal Information).

As stated in the above excerpt Kelly finds the tentativeness of scientific knowledge and creativity involved in the development of scientific knowledge to be aspects of NOS that are too difficult to understand. Such an understanding of the role of creativity in the development of scientific knowledge appears to cause her implement inquiry classes that do not require students use their creativity in their inquiries. This is probably due to her thinking that only smart people like scientists can be creative in their scientific investigations.

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Several aspects of Kelly's inquiry lesson are quite different from the other two teachers' inquiry lessons. First, Kelly's inquiry lesson is richer in hands-on content. This is not surprising because relative to the other two teachers Kelly puts more emphasis on hands-on aspect of inquiry science in explaining her views about inquiry science teaching and learning. More emphasis on hands-on aspect of inquiry may be due to her understanding that development of scientific knowledge occurs only through experimentation. When asked about the definition of an experiment Kelly states, "An experiment is a methodical process that is used to test an idea or belief. This hands-on technique tries to establish explanations by collecting data." (Kelly, VNOS Questionnaire). As seen the excerpt in her brief description of an experiment, Kelly specifically mentions the hands-on aspect of experiments but fails to mention the necessity of a controlled environment nor does she mention the purpose of establishing a cause-and-effect relationship. No mention of test and control groups in the above statements suggest that Kelly holds a misconception that all hands-on experiences students have in science classes are considered to be experiments. True experiments involve test and control groups with the purpose of establishing a cause-and-effect relationship.

Amy. Amy teaches science for several reasons:

I teach science because I love it - both the teaching and the subject matter. I want to give my students a bit of enthusiasm about the field(s) of science because I was older (late 20's) before I came to realize that "most everything is science!" I want my students to understand this early in life and in turn, to find something interesting or valuable to them personally (Amy, NOS Survey).

As stated in the above one of Amy's goal as a teacher is to make science more interesting and valuable to her students. She believes that one way to achieve this is to involve her students into inquiry learning. For Amy, in inquiry learning, discussing, questioning, and talking about things is far more important than manipulating things. The excerpt below reflects her views about the value of discussing things in inquiry learning:

I do not feel like you have to do a lot of hands-on. I think minds-on is wonderful. Why can't you do inquiry with just your mind? I do not understand why you cannot investigate something just by thinking about it and questioning it and trying to come up with a logical answer. (Amy, Interview 1, September 15, 2005)

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As seen in the above excerpt, Amy views inquiry as both a hands-on and mind-on approach to learning science. She believes the hands-on aspect of inquiry is best promoted in science labs whereas the minds-on aspect of it is best promoted in inquiry-based class discussions.

Amy's NOS conceptions are also reflected in her inquiry teaching in the classroom. Amy defines science as follows:
Science is the study of the natural world – how and why things work. It is man's quest to understand the marvels around him. It is a discipline based on evidence, observations, and careful recording and reporting of data. It is always open to further investigation (Amy, VNOS Questionnaire).

As seen in the above description for Amy, careful recording and reporting of scientific data is an important aspect of science. Such an understanding of science probably led her design inquiry classes in which lab reports constitute an important component of student inquiries. She thinks lab reports are an ideal outlet for students to effectively communicate what they did in a lab. Also, she thinks having students write lab reports using their own words enhances their analytical thinking skills because she believes expressing the results in their own words facilitates their grasp of the big picture.

Jason. Like Amy, Jason too has a somewhat sophisticated (i.e. in-between category) understanding of NOS concepts. In his teaching, he does not want to use experimentation frequently in the classroom because he tends to be disheartened by the traditional experimental mode. He does not think that traditional experiments in science classrooms are a good representation of how science works. He finds many traditional experiments done in science classrooms to be artificial. In order to represent the true nature of science, Jason thinks experiments need to be conducted by the students themselves, from start to finish, with the purpose of not just confirming what is written in the book, but also to look for anomalies. He states:

I encourage kids to come up with experimentation themselves. You are telling them [students], hey this is how science works. You look for anomalies. Then you use the tools you have to figure out an answer to that anomaly. (Jason, Interview 1, September 16, 2005)

He does not like the idea of going through a series of labs where the teacher and students know the answer before the lab is over. He thinks this way of doing labs is

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"not teaching the kids anything" (Jason, Interview1, September 16, 2005). Consistent with his understanding of how science works, Jason believes the purpose of the science labs conducted in his classroom should not be a mere verification of what they already know before they start the experiments.

For Jason, creativity is an important ingredient of all phases and aspects of a scientific inquiry. He stressed the role of creativity in the development of scientific knowledge as follows:

Science is a creative enterprise when creativity is described as the synthesis of the accepted to produce something new. This synthesis exhibits itself in planning and design (through the framing of the research question and the development of a unique experimental method), data collection (through the nuances of how the subject is observed), as well as after data collection (through the development of explanations for the phenomena observed) (Jason, NOS Discussion Board).

In accordance with his understanding the role of creativity in the development of scientific knowledge, he aims at designing inquiries in his classroom that promote student creativity. Self sustaining saltwater fish tank project is a good example of this.

I am doing something I am really excited about with my marine science class. I am having the kids design a saltwater fish tank. I am teaching pretty much everything that I need to about marine science; of both the biotic and abiotic factors of it by having them build a saltwater fish tank. We are trying to get as close to a slice of Gulf of Mexico in a fish tank as possible, trying to get as complete an ecosystem as possible. One that would function with as little human intervention as possible which has led to these incredible problems. We are looking at approximately an entire year to complete this thing. (Jason, Interview 2, September 30, 2005)

Students will have to use their creativity and reasoning in building the fish tank and, deciding which species to put in the tank and determine the right chemical and physical properties of the saltwater.

Analysis of the teacher's inquiry teaching videos using the inquiry rubric developed by the researcher reveals that Kelly's, Amy's and Jason's inquiry classes best fit the category of structured, guided and guided inquires, respectively. Amy and Kelly's inquiry lessons were similar in that they both handed out an instruction

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sheet for the inquiry lesson. However, Amy's hands-on activity differed from Kelly's in that it did not include all the steps or procedures to successfully complete the activity. In her dissection activity, Kelly provided students with all the procedures necessary to classify different bone structures using the booklet. In Amy's hands-on activity, on the other hand, the methodology section was left up to the students. Students were only provided with the materials and equipment necessary and were asked to test three possible reactions to find out which one of these reactions actually occurred. It was up to students in groups to decide which route to take in their attempts to find the actual reaction that took place.

Finally, Jason's inquiry class differed from the other teachers' in several respects. First, he does not provide any type of worksheet for the students. The inquiry project centers on achieving the unifying goal of designing a sustainable saltwater fish tank that can function with as little human intervention as possible. Second, it is not an inquiry activity that can be done in one or two class periods. Jason thinks that he can teach the entire marine science class through this single open inquiry project. Jason is the only teacher who mentions doing long-term inquiry science projects in his classroom.

Table 2 below summarizes the differences and similarities between the teachers involved in this study in regard to the enactment of inquiry learning in their science classes.

	Kelly	Amy	Jason
Relative Sophistication of NOS concepts	Naive	In-between	In-between
Emphasis on logical thinking and problem solving in lesson plan	No	Yes	Yes
Emphasis on data analysis in inquiry teaching	No	Yes	Yes
Observed Inquiry Teaching	Structured	Less Structured	Guided
Targeted Inquiry Teaching	Guided	Guided	Open

Table 2. Differences among the teachers in regards to their inquiry science planning and practices

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Discussion

This study reveals that enhancing NOS conceptions helps teachers in their efforts to integrate inquiry into their instruction by boosting their confidence in their abilities to teach science through inquiry. This study also reveals that especially teachers who lack strong science backgrounds and prior experience with inquiry science are at risk. Similar to the findings of Roehrig & Luft, (2004), having a weak science background obscures teachers' ability and/or willingness to transform their science instruction techniques from traditional to inquiry. Also, a better understanding of NOS concepts enhance teachers' familiarity with science and scientific enterprise in general and inquiry science in particular. Specifically, a better understanding of NOS conceptions helps the teachers be more discerning of the characteristics of real science as practiced by scientists. As illustrated in Jason's case, a better understanding of NOS conceptions may help teachers distinguish between real science as practiced by scientists and the distorted science as practiced in many traditional science classrooms. Such enhancements in the familiarity of the teachers with science and scientific enterprise may enhance their confidence in their ability to teach science through inquiry.

The findings of this study supports the findings of other studies in the literature in that adequate understanding of NOS conceptions is necessary but not sufficient for science teachers to successfully implement inquiry based science classes (Karakas, 2009; Lederman, 1999; Roehrig & Luft, 2004). This study is not suggesting that teachers' inquiry practices influenced solely by their NOS conceptions but rather teachers' NOS conceptions are part of the mix.

However, it appears the teachers who possess more sophisticated understanding of NOS implement less structured inquiries. Amy and Jason, who hold more sophisticated understanding of NOS, design inquiries that are more student oriented and more open ended in nature. Bencze, Bowen, & Alsop (2006) report similar findings. Specifically, they categorized teachers as having weak, moderate, and strong social constructivist views about science. They found that teachers who held strong social constructivist views about science had more of a tendency to use open-ended and student-centered inquiry activities.

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Also, regardless of the sophistification level, the teachers' NOS conceptions influence their decisions about which aspect of inquiry they emphasize in their inquiry teaching. Kelly for instance, who believes that science is procedural more than it is creative and associates doing science in her mind with being hands-on in a laboratory implements inquiry classes that are rich in hands-on content. Jason, on the other hand who associates science with being creative more than procedural incorporate inquiry into his teaching as a long term open inquires. In this open inquiry students are encouraged to use their creativity and logical thinking skills. Similarly, Amy and Jason, who consider communication skills an important component of science, emphasize a discussion-oriented approach to teaching science.

Other studies report similar findings. Lotter et al., (2007), for instance, report that teachers' NOS conceptions guide their use of inquiry-based practices in the classroom. Keys and Bryan (2000) argue that conceptions of inquiry are tied to beliefs about what science "is" and about what kinds of knowledge and skills are worth teaching in science classrooms. Southerland, Gess-Newsome, Johnston (2003) report that teachers' NOS conceptions are manifested in their classroom practices and they caution that this manifestation takes place in complicated ways. Similarly, according to Lunn (2002), the teachers' understanding of the NOS is part of "hidden curriculum" that influences how teachers teach in the classroom. He also reports that the depth of the teachers' understanding of NOS conceptions varies from one NOS conception to another. Similarly, Keys & Bryan (2001) found that teachers who hold the desired view of NOS are more likely to implement problem-based science instruction. These findings suggest that the impact of some NOS conceptions on teachers' classroom practices may be more explicit than others. In other words, the subtlety of the influence of the teachers' NOS conceptions on how they teach in the classroom may vary from one NOS conception to others. In this regard, this study supports the findings of Keys & Bryan (2001) and Lunn (2002) in that some NOS conceptions are reflected more explicitly in their teaching than others. As an example, after taking the NOS course the teachers began to ask students to base their explanations on scientific evidence. A better understanding of the subjective and empirical nature of scientific knowledge may have encouraged the teachers put more emphasis on scientific evidence in developing and defending scientific explanations. Similar findings are reported in the study of Friedrichsen, Muford, & Orgill, (2006). In this study, the authors report inquiry-teaching experiences of a former student of an inquiry

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Empowering Technologies (IET) course. This course was designed to enhance prospective teachers' science content knowledge, understanding of inquiry, and NOS conceptions. The authors found that the teacher emphasized some aspects of inquiry while deemphasizing other aspects of inquiry. Specifically, the teacher equated inquiry with the use of evidence and reflected this in his teaching by asking students to base their explanations on evidence. On the other hand, he deemphasized the tentativeness of scientific knowledge and did not incorporate it into his teaching. The teacher believed that it was not appropriate to teach tentativeness of scientific knowledge in a secondary classroom setting because it may have caused them to question the trustworthiness of the content they learned (Friedrichsen, et al., 2006).

Conclusion and Implication

This study has several implications for inquiry reform efforts. Exposing teachers to both NOS concepts and the tenets of scientific inquiry and inquiry based science teaching may expedite the science education reform efforts in schools. First, it appears that a better understanding of NOS conceptions is also conducive to achieving the objectives of the inquiry-based reform efforts because it enables the teachers to better understand the goals set forth in the reform documents, such as achieving scientific literacy. This study suggests that a better understanding of NOS conceptions enables the teachers to see the big picture of how the NOS conceptions, inquiry learning, and scientific literacy all fit together.

Second, the findings of this study suggest that professional development programs should consider teaching NOS concepts along with a method course that is concentrated on inquiry science and inquiry based science instruction. Adopting such an approach may also expedite inquiry based science education reform in schools. As was the case in this study, it may be more beneficial to teachers if the explicit and reflective NOS instruction is accompanied by an inquiry science method course where teachers engage in inquiry science and reflect on their inquiry experiences and their future plans to integrate inquiry science into their science instruction.

Finally, a better understanding of NOS concepts assists the teachers to develop a higher appreciation of inquiry science instruction. It helps them develop a new

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perspective of science and science instruction. Adopting explicit and reflective instruction in these programs appears to be the most conducive approach to improving teachers' NOS conceptions (Khishfe & Abd-El-Khalick, 2002; Schwartz, Lederman, & Crawford, 2004).

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