Preparing Future Science Educators: Changes in Nature of Science Views and Practices during a Graduate Program

Renee' Schwartz, PhD.
r.schwartz@wmich.edu
Department of Biological Sciences, The Mallinson Institute for Science Education
3139 Wood Hall, Western Michigan University, Kalamazoo, MI 49008

Brandy Skjold
George Akom
Hang-Hwa Hong
Fang Huang
Robert Kagumba
The Mallinson Institute for Science Education
Western Michigan University, Kalamazoo, MI 49008

Abstract

Nature of Science [NOS] is a component of scientific literacy. Much current NOS research has focused on K-12 teacher development. Today's science educators not only conduct much of this research, but are also charged with preparing future science teachers to effectively teach NOS. Yet we know little about the professional preparation of science educators as they develop NOS expertise. This study begins exploring such developments by examining the experiences of five science education graduate students as they learn about NOS content, pedagogy and research during the first two years of a graduate program. The participants are culturally diverse, representing five different countries. Influential factors are identified as the students developed personal orientations toward NOS. The change in NOS views and teaching perspectives were multifaceted. Motivation shifted from primarily external sources such as course requirements, to internal factors relating to conceptions of "good science teaching" and goals as science educators. Personal motivations were especially instrumental regarding perceived value of NOS to science learners in non-Western cultures. Establishing a consistent NOS focus throughout graduate programs; providing multiple exposures and supports; and building upon students' internal motivations in science education are recommended for enabling future science educators to bring to bear NOS literacy goals.

Earlier versions of this paper were presented at the International conference of the National Association for Research in Science Teaching, New Orleans, LA. 2007. and the annual conference of the American Educational Researchers Association, New York, NY, 2008.

"What does/should the professional development of the science education professoriate look like?" (Abell,1997). When Sandra Abell asked this question over 10 years ago, she called for our commitment to better understand the growth and knowledge base of science teacher educators. She also asked, "Why is it that science educators have little to say about their own or their graduate students' professional development?" (Abell,1997). These concerns stem from the limited, at best, research focused on developing science educators as teachers and scholars. In response, the Association for Science Teacher Education (ASTE, formerly AETS) developed *Professional Knowledge Standards for Science Teacher Educators* in 1997 (AETS, 1997). These standards apply to "Science Teacher Educators," who include: (a) Faculty in higher education who provide course work in science subject matter and/or science pedagogy; (b) School-based mentor teachers; (c) Personnel in schools who provide professional development; and (d) Personnel from agencies other than universities or schools who provide instruction or resources for professional development.

These standards state that science teacher educators should have knowledge about the philosophy, sociology, and history of science. Teachers need to be articulate in current perspectives of Nature of Science [NOS] and knowledgeable of difficulties learners have with conceptual and pedagogical developments. In the 10 years since the development of the Professional Knowledge Standards, we still know very little about how science educators develop as professionals in general, or how they develop NOS conceptual and pedagogical knowledge, specifically.

To begin addressing these questions, we must consider science educators' backgrounds in science learning. Research continues to report learners' misconceptions about NOS, and these views relate to lack of NOS instruction or misrepresentation of NOS within science classes (Lederman, 2007). Undergraduates (majors, nonmajors, preservice teachers) continue to describe science as "truth seeking," where the "scientific method" produces data in an objective way that reveals absolute answers (Abd-El-Khalick, 2001, 2004; Akerson, Morrison, & McDuffie, 2006; Hanuscin, Akerson, & Phillipson-Mower, 2006; Gess-Newsome, 2002; Ryder, Leach, & Driver, 1999; Smith & Scharmann, 2008). Thus, graduate students in science education, a.k.a. the future scholars of science teaching and learning, are products of a tradition that counters current perspectives on NOS (AAAS, 1993; Lederman, 2007; NRC, 2000).

In addition to science instructional background, we should consider the various paths that lead to a career in science education. Most students entering science education graduate programs typically originate from K-12 teaching communities or science research communities. They have experienced a goal transition from science teaching or conducting science research, toward examining science teaching and learning from the perspective of research and teacher education. Science educators who teach and mentor these beginning scholars need to have an understanding of their perspectives and developments as learners. Such understanding is imperative to building and sustaining systemic reform toward scientific literacy (Abell, 1997). As it stands, these future scholars are an untapped pool of learners when it comes to understanding how they develop conceptions of NOS and NOS teaching (Irez, 2006). What are their motivations? What are their challenges? What experiences impact their views of NOS and science teaching? What experiences impact their teaching? How do they view themselves as learners and teachers of NOS? Our graduate students are the future leaders of science education. These are critical questions that warrant investigation. The current study reports the personal stories of five science education graduate students. This is a report of self-reflection, where the students assume a metacognitive perspective to examine developments in learning, teaching, and orientations toward NOS during their graduate program. This paper characterizes experiential and personal factors that mediate developments.

Nature of Science

Nature of science [NOS] refers to the qualities and assumptions that are intrinsic to the products of scientific inquiry (i.e. scientific knowledge) (Lederman, 2007). Although there are multiple descriptions of NOS, the current study is based on generally agreed upon tenets relevant to K-16 science education (Abd-El-Khalick, Bell, & Lederman, 1998; McComas & Olson, 1998; NRC, 1996; Osborne, Collins, Ratcliffe, Millar & Duschl, 2003). Scientific knowledge is (a) *tentative* (subject to change*);* has basis in (b) *empirical evidence;* (c) is the product of human *imagination and creativity*; (d) involves both *observation and inference*; and (e) is influenced by current scientific perspectives (*theory-laden* observations and interpretations) as well as *personal subjectivity* due to scientists' values, knowledge, and prior experiences. Another feature of scientific knowledge is (f) the functional difference and relative status between *scientific theories and laws.* Often associated with NOS, but more aligned with the nature of scientific inquiry (Author et al., 2008), is that (g) there is *no single scientific method.* Rather, investigations may take a variety of forms depending on the questions being addressed. While explaining the inherent tentativeness of science, these aspects also reinforce the durability of scientific knowledge. For example, understanding the empirical NOS serves to counter an "anything goes" perspective that may be inappropriately associated with the notion of 'subjectivity.' Scientific knowledge is founded in data which are subject to interpretation (necessarily a theory-laden and socially influenced negotiation) and accepted within the community based on standards of said community. Some knowledge may be more robust than other because of the supporting empirical data. Nonetheless, all scientific knowledge is subject to revision through renegotiation of available data..

LITERATURE REVIEW

Developing Teachers' Knowledge of NOS

Science educators have been examining how students and teachers learn NOS and effective means of teaching NOS. Implicit approaches are not as successful as explicit approaches in aiding learners' NOS conceptual development (Khishfe & Abe-El-Khalick, 2002; Lederman, 2007). Contexts for inquiry experiences and guided reflection *on* those experiences are influential to NOS learning (Author et al., 2004; Bianchini & Colburn, 2000; Lederman, 2007; Smith & Scharmann, 2008). Extant research exploring means of effective teaching about NOS consistently emphasize teachers' needs regarding NOS knowledge, pedagogical knowledge, internalized beliefs in the importance of NOS, and intentional translation of this knowledge into explicit/reflective classroom instruction (Akerson & Abd-El-Khalick, 2003; Author et al., 2002; Bartholomew et al., 2004; Khishfe & Abd-El-Khkalick, 2002; Lederman, 2007). Further, there may be associations between teachers' views of NOS and views of science teaching and learning (Tsai, 2002). Science educators conduct much of this research targeting K-16 teachers and learners of science. They not only need to have knowledge within the same domains as K-16 teachers, they have the added requirement, as science teacher educators, of having expertise in teaching teachers concepts of NOS and NOS teaching. Few studies have examined the NOS knowledge or pedagogical developments of science educators.

Irez (2006) examined NOS views of 15 Turkish future science teacher educators. Through analysis of interviews and cognitive maps, Irez determined the participants held inadequate conceptions, especially relative to scientific method and the tentativeness of scientific knowledge. Twelve of the 15 agreed that there was a single, universal, scientific method. Sixty percent reported absolutist views of science, seeing "scientific laws as the final form of scientific knowledge representing truth and, therefore, not subject to change" (Irez, 2006, p. 1127). Irez reported a lack of previous interest in and reflection about NOS likely contributed to the participants' views. Further, the content-based science curriculum that prepares the future scholars may be a contributing factor. "As the products of such an education, it is not surprising that these participants were left with a range of misconceptions or naïve beliefs about NOS" (p. 1137). Irez suggests that such inadequate conceptions could be detrimental on practical (classroom) and policy levels (science teacher education programs).

Volkmann and Zgagacz (2004) investigated the learning experiences of a graduate student as she taught an undergraduate inquiry-based physics course. By utilizing orientation and identity frameworks, they determined that NOS beliefs may relate to teaching orientations. Change in teacher identity and teaching orientation requires reflection on views and practice. The authors pose several recommendations for science education programs, including consistency with promoting inquiry orientations and course work in teaching and learning of NOS.

More research has explored developments in preservice teachers. Multiple experiences that reinforce and challenge learners to reflect on personal NOS views and practices are recommended for promoting and internalizing NOS views of K-12 preservice science teachers (e.g. Akerson et al., 2006; Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001; Smith & Scharmann, 2008). In a study of preservice elementary teachers, Akerson et al. (2006) examined retention of NOS views 5 months after a science methods course that emphasized explicit/reflective NOS. They found that despite enhanced views immediately after the methods course, several had reverted back to their more naïve NOS views. Akerson et al. suggest possible strategies to improve conceptual development, including use of metacognitive strategies and prompts to contextualize their views within classroom activities. Indeed prior research demonstrates the effectiveness of aiding teachers' NOS views and abilities to teach NOS by offering examples of content-embedded NOS instruction and support with implementation (Akerson & Abd-El-Khalick, 2003; Hanuscin et al., 2006; Lederman et al., 2001).

PURPOSE OF THE STUDY

Given the needs of science teacher educators and given the requirements for effective learning and teaching of NOS, there is a need to explore how science education programs (1) affect future science educators' views of NOS and (2) influence their abilities to translate views into teaching practice and decisions regarding curriculum development. With respect to five graduate students in science education, the research questions are:

1. How do NOS conceptions change during the graduate program?
2. How do NOS teaching practices change during the graduate program?
3. What experiences and factors impact NOS conceptual knowledge and practices?

METHODS

We drew from multiple case study and self study perspectives to explore personal developments that would inform our research questions. Case studies are useful to closely examine an event or program, or to look at the responses of multiple individuals. This approach applies when a case can be bounded either by time or by place, but more importantly the case must lend information on a currently existing problem (Creswell et al., 2007). This particular research is framed within required program experiences of five graduate students.

This research relates to self-study, in that five of the researchers are also the participants, studying their own developments in learning and teaching over time. Through self reflections, the group explored personal experiences, personal developments, and personal beliefs. Self-study allows the researcher to admit personal interest in a particular phenomenon, while allowing for personal intellectual and professional growth of the researcher (Bullough Jr. & Pinnegar, 2001). The primary researcher, not a participant, served to guide the reflections and data analysis.

We also adopted a constructivist, interpretive, approach. By exploring and describing science education graduate students' experiences vis-à-vis the learning and teaching of NOS, the study aims at making "meaning within a natural setting" (Williamson, Schauder, Wright, & Stockfield, 2002). Darke, Shanks, and Broadbent (1998) state that the interpretive approach is based on the "ontology in which reality is subjective, a social product constructed and interpreted by humans as social actors according to their beliefs and value systems."

Participants

The participant-researchers are five graduate students in science education (Table 1). Four of the five were working toward a Ph.D. in Science Education and the fifth was working toward a Master's Degree in Science Education and has since begun doctoral work. When the study began, three were in their first year in their respective programs and two were in their second year. Four students have previous teaching experience at the middle school, high school or undergraduate science. All five have a Bachelor's degree in a science area; four hold Master's degrees, and one has a PhD. The group is culturally diverse, each originating and being educated in a different country. Only one, Brandy, said she had heard of NOS prior to the beginning of the study. All were supported through assistantships teaching undergraduate science courses.

Context of the study

The science education graduate program is housed within the College of Arts and Sciences at a large Midwestern university. The science education institute has 10 faculty members and approximately 15 full-time graduate students. Courses, research, and teaching experiences provided the context for the study.

The study began with all five students (participant-researchers) enrolled in a Research Traditions Course which focused on NOS. The primary researcher (first author) was the instructor of the course. The following semester, the primary researcher and five participant-researchers formed a NOS research group to meet and discuss activities related to NOS research and teaching. All five students were then enrolled in a second course taught by the primary researcher. This was a teaching methods course which extolled the use of NOS and inquiry in science instruction at the college level. After the completion of the second course, our NOS research group met periodically for several months to discuss progress on current and past research projects. All of the students taught undergraduate courses in their preferred discipline during the entire span of this project. Each of these elements is described more fully below, in chronological order. This project spanned approximately 20 months.

<u>The Research Traditions Course</u>

In the fall of 2005, the topic of the Research Traditions course was "Perspectives and practices of research in Nature of Science." The class met 3 hours a week for 15 weeks. This course focused on what NOS is, what and how research on views of NOS has been conducted, current issues in NOS research, and future directions for NOS research. The goals of the course included that students will (1) gain knowledge and experience with past and current NOS assessments, research practices, and teaching practices, (2) conduct a literature review, and (3) prepare a research proposal for investigating NOS views and/or teaching. The beginning of the semester focused on developing conceptions of NOS by engaging in numerous NOS activities, discussions, personal and group reflections. Students initial NOS views were elicited through the VNOS-C survey (Lederman et al., 2002) and follow up group discussion. Instruction modeled an explicit/reflective approach to teach NOS. Group activities such as "the tube," "tricky tracks," "pattern cubes," and "fossil fragments" (Lederman & Abd-El-Khalick, 1998) and "mystery bones" (Lederman & Lederman, 2005), readings from philosophy of science (e.g. Thomas Kuhn) and science education (complete reading list available upon request) further introduced NOS aspects and prompted reflective discussions. Through discussions, students were asked to compare their initial views with those presented through the course. Various assignments required them to explicitly write about their NOS views, views of the place of NOS within science teaching, and reactions to readings. The next segments of the course focused on traditions of NOS assessments, research techniques, and the progression of research in NOS teaching and learning. Assignments included readings and reflective writings about philosophy of science and science education literature, observations/reflections of science teaching, observations/reflections of science research, interviews with college science instructors and scientists, analysis of various NOS assessments, analysis of sample VNOS written and interview responses, and preparation/presentation of a NOS research proposal. Throughout the course we held discussions about how views have been challenged, why, and the impact on views and practice of science teaching.

NOS Research Meetings I

In the spring of 2006, we formed a NOS research group in order to continue conversations and conduct various NOS-related research projects designed during the research course. The group met several times over the semester and summer to discuss research progress, goals, and findings. Four of the five students conducted their proposed study during a qualitative practicum course the spring 2006 semester, taught through a different department. George decided not to pursue his original proposed study at that time, realizing the difficulty with finding middle school teachers who teach both NOS and history of science. Three have completed their studies. One presented her study at a conference (Authors et al., 2006).

It was during these meetings that we decided to explore more deeply how the graduate students' learning and teaching of NOS were developing. The group met several times over the next six months to track developments and capture reflections. The data collected included field notes from group discussions and a personal statement written by each participant that described their learning experiences and personal journeys since the beginning of the NOS research course.

The College Science Methods Course

In the fall of 2006, the same five students took a methods course for college science teaching, taught by the same faculty member (Author, 2008). There were 11 students total in the course, all graduate students in science education. The course met for three hours, once a week for 15 weeks. The course emphasized "active learning" and teaching of NOS within all science disciplines, and within a variety of instructional strategies and contexts (e.g. large lecture, discussion, laboratory, inductive, and deductive approaches). The course included model lessons, readings, reflective writings, and discussions targeting explicit/reflective NOS pedagogy embedded within science content courses. Students conducted classroom observations and interviews of university faculty, aiming to elucidate enacted and perceived objectives, including NOS. They were asked to describe the image of science portrayed in the observed classes and expressed by the instructors, the demonstrated roles of the instructors and learners, and how these align with constructivist perspectives and current views of NOS. Self (through video-taping) and peer observations of teaching in the undergraduate science courses also enabled focused attention on NOS, in addition to other teaching and learning factors of interest to the students (e.g. management, questioning strategies, levels of inquiry, etc.). Students designed a syllabus and full unit lesson plans for an introductory undergraduate science course, where they were required to include goals and objectives for NOS, explicit/reflective NOS instruction, and NOS assessments. Students were required to include NOS objectives within their model lesson plans for a lecture and a laboratory session. They were also required to design and present an inquiry-based lesson that targeted NOS aspects tied with other science content. Knowledge of college students as learners, typical misconceptions about NOS and other science content, goals of reform in science education, and the role of college science instructors were emphasized throughout the course.

NOS Research Meetings II

The research group met several more times over the next four months to further discuss NOS views, teaching practices, facilitators and barriers. The participant researchers wrote final impact statements which described their total experiences with teaching and learning NOS. The guideline for this was developed by all group members. We met to analyze and discuss the final impact statements. This meeting was recorded through video-tape and notes. This session was designed as a roundtable discussion in which the primary researcher asked questions to clarify data obtained from all previous sources.

Data Sources and Analysis

We examined the phenomenon of learning about NOS from within a real life context (the daily experiences of the graduate students in the program) (Yin, 1994). Data collection spanned nearly 20 months and data analysis proceeded in an iterative fashion. Data sources comprised the initial NOS survey, reflective writings (narratives and written impact statements), field notes from discussions and meetings, and a videotaped group discussion. Data were analyzed through a constant comparative method, in that themes emerged from initial data sources and comparisons, refinements, and additions were made as necessary throughout the study.

Personal Narratives

As a result of the NOS research meetings during the summer of 2006, the group planned to capture personal experiences and reflections from the year that related to their growth in understanding, teaching, and research on NOS. The purpose was to identify themes from these experiences and how they might affect NOS learning as well as the future teaching and research endeavors of the graduate students. One of the participants designed a guideline for the narratives which served as a starting point for generating and organizing the reflections (Appendix). The guidelines include providing background information about education and work experience, initial perspectives on NOS, significant events in understanding NOS, future expectations of using NOS, and problems encountered in both learning and applying NOS. None of the participants read or advised any of the others on their writing to ensure that all responses were accurate individual assessments of personal experiences. These narratives were analyzed inductively (Bogdin & Biklin, 1990) to identify themes among experiences and perspectives.

NOS research group discussions focused on experiences, challenges, successes, and developments in views and teaching practices. The first author documented these discussions through field notes. Experiences and influences from the methods course were included in a "final impact statement" (Appendix). Collectively, the two personal statements provided a comprehensive reflection on learning experiences and personal developments throughout the year. Each participant reviewed all the statements and provided initial analysis to identify common themes represented by the group. We held a group discussion to share analyses, review the reflections, and gain consensus on themes from the data. The "trustworthiness of inferences drawn from the data" was ensured through the self-study and reflective comparisons (Eisenhart & Howe, 1992). The first author reviewed all data again for confirming and disconfirming instances, further reducing and altering the categories as needed to describe types of experiences and personal factors that represent the graduate students' learning of NOS. All participants provided review and final consensus.

NOS Questionnaire

Data also included responses to the VNOS-C questionnaire that participants provided during their first week of the initial course. These responses served two purposes. First, they provided description of initial views, analyzed through the method of Lederman et al. (2002). Second, they provided a baseline for comparison and reflection. Throughout the discussion sessions, participants could refer to their initial ideas to reflect upon how their views have developed. Given the nature of the discussions and course assignments, it was not informative to request post-VNOS responses. The students had become familiar with typical "naïve" and "informed" responses (Lederman et al., 2002) from reading and discussing literature and practicing VNOS analysis.

RESULTS

The results are presented first through summary of the graduate students personal impact statements that describe reactions and turning points. These summaries are in the participants' own voice, and give an indication of the unique perspectives each graduate student associates with NOS. They also show how all five students went down a common path, leading from confusion to enlightenment regarding their understanding and application of NOS. They also demonstrate distinct differences in orientations and motivations. Second, initial NOS views and changes in views are summarized (research question #1). Next, we describe NOS teaching attempts and challenges (research question #2). Finally, the bulk of the results address research question #3. We describe factors and experiences that impacted these graduate students NOS views and practices. Statements of personal voice are representative of reflections and intend to inform the reader of our inferences.

Personal Reflections: Perspectives and Impacts

Brandy

Before taking the course on NOS research, I was frustrated and confused by my past experiences in science. Most of my coursework and teaching had been in Biology. I had always been taught that science is important and absolutely fundamental in education. I was given the impression that it deserved a place of prominence when compared to other subjects. However, my experiences in the [research] labs and the classroom led me to believe that science was arbitrary and subjective. I had a difficult time trying to justify this and was becoming frustrated with science in general. I was also finding it difficult to be confident in teaching the subject because I was losing interest in it. After taking the nature of science course I realized that subjectivity, creativity and tentativeness are a part of science. However, I no longer feel this reduces science's credibility, because I no longer see science as being more important than other subjects. I was holding science to a different, and inappropriate, standard than other types of study. This new realization allowed me to justify my interest in it, has given me a new confidence to teach science. I feel I now truly understand what I am teaching and I can discern appropriate situations in which science should be emphasized…..I tend to concentrate on the areas of law and theory, especially when discussing evolution. I also incorporate tentativeness and social/cultural aspects into lectures, often through the use of historical perspectives on the topics….I tend to miss opportunities to discuss creativity, which I could incorporate into small group modeling activities I do. I also tend to avoid the idea of empirical knowledge, because I have a difficult time distinguishing it from objectivity (versus subjectivity, which I often incorporate into discussion on social/cultural contexts). The roadblock I have in teaching NOS is the students I am teaching, as well as other faculty. Students get frustrated when asked to learn in ways they have never learned before [use of inquiry]. They have learned that science is something different from what I am teaching them…[Note: Brandy has incorporated explicit/reflective NOS instruction into an undergraduate biology course for elementary education majors, under the supervision of the primary researcher.]

Fang

As Chinese, we are growing up in an environment that the dominant dogma is materialism… In our mind, science represents truth, equality, and authority. Few of us ever questioned the rules, theory, or the law of theory we learned. I first heard about NOS in the research course. My feeling was like walking in a maze, having not even a little clue, which is very uncomfortable. It was hard to change and accept an almost opposite view. I did not get the idea of NOS until after experiencing formal instruction, authentic observation and group discussion for about two months. It was a gradual process, from doubting and unbelieving, to confusing, and understanding and believing finally. I felt shocked since the perceptions of science that have been rooted in my mind for over twenty years suddenly had to change. The most effective experiences were the hands-on NOS activities and minds-on questions from the class. Discussions made me clarify and deepen my personal understanding. I think this is a crucial part for people to understand NOS. The other impressive experience was observing a science Ph.D student. I could describe aspects of NOS in his work. However, as a teacher, I still feel difficult to put NOS in my lecture. What is the good topic and what is the good time to insert NOS are two big problems for me. After summer 2006, I took the college methods course and prepared for the comprehensive examination about NOS. [These experiences (reading of more research, practical application through lesson planning)] helped me develop deeper understanding of NOS, and made me to understand how to design a NOS lesson within science context and how to teach. To speak in detail beyond what is the meaning of NOS and how to assess people's view of NOS that taught before, both the method course and preparation of comps broadened my knowledge of NOS. Comparing what I learned before which is more theoretical, these knowledge helped me realize the value, the meaning, and the usage of NOS research. In other word, these knowledge made me to understand the importance of NOS, which actually improved my motivation in learning NOS. Understanding NOS does not mean being able to teach it. I have the same problem as many teachers described in many researches. I was able to tell students what the meaning of NOS, for example what the subjectivity of science means. But I can only explain it with very limited sentences that learned from the articles. I felt that my lecture of NOS would be very abstract and boring. So at that time, I did not have enough courage and belief to teach NOS. The methods course provided some good examples of teaching NOS in science context, which make me to get familiar with this type of class and get a sense of how to teach NOS in a science context. The assignment of NOS teaching plan in this course has the direct effect on my view of NOS teaching. Under the pressure of the assignment, I started to think seriously how to design a class. It took me some time and efforts on searching materials, examples discussing with colleagues, but it was really a very good experience. After some hard work, some ideas came up. I started to understand where to put NOS in the science context and how to integrate both NOS and subject knowledge to teach. This experience not only helped me learn how to teach NOS, but also improved my confidence in NOS teaching.

<u>Hang-Hwa</u>

I'm a scientist and also a science teacher educator. The NOS research course was the first time for me to learn and to think about NOS. At that time, I didn't realize that to know the knowledge of NOS could help me to understand and to expand my ideas for science. Now, I'm sure that NOS will help pupils to be interested to do science. I first thought that NOS was very easy and common for scientists. However, when I got a question about "What is the NOS?" I couldn't answer it quickly. The main experiences that impacted my knowledge were realizing my uncertain ideas for NOS, having an expert who could check my ideas for NOS, and then trying to teach NOS to inservice and preservice teachers. As I prepared to teach a methods course in my country [during the summer], I reviewed the NOS materials and publications. I discussed with the students about NOS. The aspects of NOS became clearer to me. Teaching experience gave me an assurance to teach NOS explicitly. The students reflected that if NOS is taught explicitly, their pupils could feel that science is very interesting instead of boring. I now have many ideas for research in science education. I conducted a research study of Korean preservice elementary teachers' NOS views. Conducting the interviews and analyzing the data impacted my NOS views. I had to reread the NOS articles because I want to get clearer framework for research analysis. At that moment, I could find more information from references. I'm pretty sure that information already there when I read it, however, I just ignore some points because I didn't realize that those information in every each line are important for my research. If I stopped in there to think about NOS aspect after the [first NOS research] course, I might stop to keep different views of NOS and probably back to chaos about aspects of NOS. Teaching is a good chance to think more deeply about aspects of NOS since it was a challenge to say aspects of NOS explicitly and research procedures also helped me as a kind of beginner of informed view of NOS. [Note: Hang Hwa has incorporated explicit/reflective NOS instruction into an undergraduate biology course for elementary education majors, under the supervision of the primary researcher.]

George

Coming from Anglophone Cameroon where is a tradition of discipline-specific science teaching and learning, I went through many 'missed opportunities' in my struggle to understand what science really is. I knew science as a compartmentalized body of undisputable facts which was done by following a rigid set of procedures. There is the unavoidable reliance on textbooks which are like Bibles. From this perspective, it does not matter if students understand how scientific knowledge is developed. What is important is making the grades and going out to get a job. Later as a science teacher and trainer the cycle was to continue. NOS eluded me till twenty-five years after my formal initiation into science. With my enrolment into a graduate program in science education and taking a NOS research course my perspective of science and science education was to be dramatically overhauled. At first it did not make much sense to me. It was only through careful reflection that I could come to terms with 'this stuff known as NOS'. I do not only see science now as this body of knowledge and processes which students have to know so as to pass exams, but also as a way of knowing. At this moment I cannot stop wondering if Cameroonian students are actually becoming scientifically literate and what effect this has on the society. This leaves me thinking about what can be done in bringing about a change in the teaching and learning of science in Cameroon.

Through subsequent courses I have been able to put into practice some of the ideas I learned in the research course. Two courses involving learning theories and college science teaching have helped me shape my ideas and use of NOS. During these courses there have been opportunities to incorporate aspects of NOS in the learning process, most significant of which were the creating of lesson plans and presenting of micro-lessons. This helped me face and overcome the challenges involved in understanding and teaching NOS. I had to re-read some writings on NOS in order to properly use them. Through use of NOS I became more confident and motivated to incorporate NOS in my teaching. I am able to freely include and discuss many aspects of NOS during my lessons. A very important discovery for me has been the use of history in the teaching of NOS. I feel my teaching has improved because I am able to explain certain issues in science to my students in more appropriate and convincing manner. I still struggle a bit with explaining aspects such as the distinction between theories and laws to the students. The engrained nature of their earlier views makes it more challenging for me. This hasn't been free of frustration for me. My greatest frustration has been having some students still asking for "right answers" or "right procedures." However, I think I am expecting a fast change when it was not that easy for me to understand some of the aspects of NOS. This consoles me and teaches me to be persistent but gentle in guiding students to an appreciation of NOS. I am learning more and more about NOS as time goes by.

Robert

Since my primary education I had been told that science establishes facts that are very close to the truth and if science says, it is so. I had been told and I had learned that science made such great progress and advancement because of its tested and proven scientific method. These were my thoughts coming into the graduate program. Funny, but at the end of the first session of the NOS research course, I was in denial. Letting go of the scientific method was a very great problem for me until I internalized the role creativity plays in science. It was new to me to know that there are values and norms that govern science and its products. Something that gave me confidence to associate freely with the body of knowledge called science for my life is really the value laden NOS. It was a great relief for me to know that there are social cultural values carried with every scientific endeavor. This realization gave me a boost of self esteem for then I knew that African science can be accepted as a contribution to the global scientific movement. Remember I came into the [NOS research] class knowing that the globally accepted science is western science. The class activities like the Mystery tube, the foot prints, etc., and the group discussions played a great role in helping me learn **about** science instead of science. Right now I can try to evaluate scientific statements; I can participate comfortably in science related debates. My confidence to voice out my scientific opinions has greatly improved and my science teaching has greatly improved. Now I can teach through inquiry with a little bit more confidence than before. Even with all this long strides into the better understanding about science, I've needed help especially in the pedagogical content knowledge (PCK) area to enable me teach NOS with confidence. The college science methods course greatly helped me acquire the PCK to teach NOS. The methods course helped me acquire the strategy to identify the learner's misconception and come up with an activity that will help that learner drop their conception. Moreover, take on the accepted scientific conception. The different peer teaching presentations from various scientific disciplines helped me polish up and internalize further NOS. I also studied the phenomenon of teaching NOS in the middle school. I gained great insights into the NOS views of middle school teachers. I also come to appreciate that the teachers do not differentiate clearly about teaching by inquiry and teaching NOS. This makes them unable to plan to teach NOS; those who try, they do it implicitly.

My view of science as a conscious human activity has been greatly strengthened. I have with greater confidence to discuss and explore other opinions in class. I found out that the tentativeness, empirical, observation vs. inference, creativity and subjective aspects of NOS are easy to embed in my teaching material. At least I plan with fair ease to incorporate any of these in my lessons. The social cultural context and functional relationships of theory and law have been the hardest to embed in my teaching material.

How do NOS Conceptions Change during a Graduate Program?

The VNOS-C and initial discussions elicited conceptions of eight NOS aspects (tentativeness, subjectivity, creativity, empirical NOS, difference between observation and inference, difference between theory and law, sociocultural embeddedness of science, multiple scientific methods). All of the graduate students began with fairly positivist perspectives of NOS.

Four of the five reported being comfortable with the ideas that science is objective, authoritative, and value-free. Three of the five reported that there is a single scientific method. The two who considered multiple investigative approaches (Brandy and Hang Hwa) were the only two to also initially describe the role of creativity in developing scientific knowledge. Only one, Brandy, viewed scientific knowledge as inherently tentative. Overall Brandy held views more aligned with current NOS perspectives than the others. Her VNOS responses indicated consistency with current views on seven of the eight aspects. The others held traditionally naïve views (Lederman et al., 2002) of most aspects. Robert was the only one to describe a functional difference between theories and laws, although he still thought scientific knowledge could be absolute and objective.

The participants indicated dramatic positive shifts in their conceptual understanding and affective commitments to NOS. They were able to articulate informed descriptions (Lederman et al., 2002) of most aspects, as evidenced through discussions and writings. We feel that for the purposes of advancing NOS research, it is sufficient to report that these students achieved the desired conceptual advances, and then focus more thoroughly on the results of how they got there. In the summaries of personal reflections, the graduate students described their advances and personal reasons for their views. We present identified influential features later in this paper.

How do NOS Teaching Practices Change during a Graduate Program?

Teaching Attempts

All five reported not having taught about NOS previous to the program. All five reported success, to different degrees, in incorporating explicit/reflective NOS into their undergraduate science courses during the program. Brandy and HangHwa were under the supervision of the primary researcher to plan and teach their biology classes. NOS was already embedded through objectives, instruction, and assessments. Nonetheless, they needed to negotiate for themselves how best to address relevant NOS aspects within the biology context. George, Robert, and Fang had more independence with their NOS teaching choices. Review of videotaped teaching sessions (a requirement for the method class) supported self-reports of NOS teaching. Most commonly taught NOS aspects addressed were tentativeness, subjectivity, observation and inference, and multiple scientific methods. For all five, finding appropriate contexts to distinguishing between theory and law and teaching about the social and cultural NOS were more difficult.

George embraced the use of history of science to address NOS topics in his chemistry class. For example, he used historical models of atomic structure to discuss social/cultural influences, tentativeness, and observation/inference. George would ask students to make connections from examples and NOS. As the semester progressed, he reports increased confidence and insight into how to utilize historical examples to teach NOS. “I incorporate NOS with everything now.”

Robert, HangHwa, and Brandy utilized group discussion to raise NOS connections within science contexts. Through questioning strategies, they aimed to challenge students to think about how class activities and investigations represent specific aspects of NOS. Robert embraced the essence of creativity and social/cultural influences. He wants his students to know that their ideas are important and that everyone can be successful with science. His prior view of teaching science as factual, through methodical procedures, is gone. Nonetheless, there are challenges with implementing this new perspective.

Challenges with Teaching NOS

Challenges spanned from curricular restrictions to feelings of low efficacy in abilities to teach NOS. All participants recognized the need for informed NOS views as well as multiple examples that mesh with the science content of their courses. Although they report a better understanding of NOS, teaching was another matter, at least initially. Challenges with teaching the undergraduate science courses stemmed from not seeing connections between NOS and the science content, not explicitly planning to teach NOS, and having to maintain consistency with the other sections of the course. The undergraduate courses have multiple sections, taught by other graduate students and faculty. The teaching teams for respective science courses meet weekly to discuss upcoming lessons. With the exception of Brandy and HangHwa, the participants reported that these meetings either never did, or did so sporadically; attend to embedding NOS within the specific content. These external constraints were barriers, but only to an extent. Internal motivations for teaching NOS needed to surface through asking such questions as “How important is NOS to my students?” We discuss below external and internal factors influencing successful teaching practice as they relate to conceptual knowledge, efficacy, and pedagogical content knowledge.

What Experiences and Factors Impact NOS Conceptual Knowledge and Practices?

Themes of perceived influential factors emerged from review of all the data. We describe these themes alongside representative quotes to support inferences. Many of the quotes are also presented within the individual summary statements above.

Initial Reactions to and Rationales about NOS Views

The Novelty of NOS

At the beginning of the program, none of the graduate students had ever considered NOS in an explicit manner. The novelty of NOS surprised them, especially given their science backgrounds. Although Brandy had rather informed conceptions of NOS, she, like all the others really had not heard of NOS before the research course.

> I had no idea what [NOS] was or why anyone would have studied it. I assumed it [NOS research course] was going to be a discussion about each of the four major science disciplines. When I finally did realize that NOS was simply about science in general and what it is, I was relatively taken aback. It has never occurred to me that someone could define science… [Brandy, initial narrative]

> It was a gradual process, from doubting and unbelieving, to confusing, and understanding and believing finally. I felt shocked since the perceptions of science that have been rooted in my mind for over twenty years suddenly had to change. [Fang, initial narrative]

> Since my primary education I had been told that science establishes facts that are very close to the truth and if science says, it is so. I had been told and I had learned that science made such great progress and advancement because of its tested and proven scientific method. These were my thoughts coming into the graduate program. Funny, but at the end of the first session of the NOS research course, I was in denial. [Robert, initial narrative]

Prior Science Learning and Teaching Experiences: Awareness of the Disconnect between How Science is Taught and NOS

As depicted in Robert's quote above, prior science learning and teaching experiences was considered a source of initial views.

> I was always taught science in this [absolute] way. So that is how I always thought science is. [George, initial narrative]

> I am a scientist and also a science teacher educator….[NOS research course] was the first time for me to learn and to think about the NOS. [HangHwa, initial narrative]

> The NOS was foreign to me, even as a graduate student. I was taught that one thing that has made science very successful is the scientific method. I knew that this method was universal, there by making science universal…I knew that science was very objective and free of values. I had this mind set that there is only one science through out all cultures and it was not a social construct at all. Science was there and men and women just discovered it. [Robert, final narrative]

Cultural Influences

All five participants were raised and educated in a different country (Table 1). In discussions about prior experiences and embedded perspectives about science, participants' cultural origins and worldviews provided rationale.

> As Chinese, we are growing up in an environment that the dominant dogma is materialism. From elementary school, we have been taught that there is no divinity or supernatural beings, all the legends are fictive, all that we can believe is the true and absolute material world. Subsequently, in terms of science, we trust it, and respect scientists as well since in our mind. We believe without any doubts that scientists strictly follow well-designed procedure. In our mind, science represents truth, equality, and authority. Few of us ever questioned the rules, theory, or the law of theory we learned. [Fang, initial narrative]

> I came into the [NOS research] class knowing that the globally accepted science is western science. [Robert, final narrative]

Factors Influencing Change

Both external and internal (personal) factors seemed to impact NOS views and practices. External factors relate to programmatic components (things the graduate students had to do). Internal factors relate to personal motivations as science educators. At times the relative effects may be indistinguishable; as internal motivations may be triggered through external pressures of course assignments. Motivations to succeed may manifest through external impulses. The following categories represent the reported influential features of student experience, but the effects of any one should not be considered in isolation.

What Experiences had a Positive Impact?

The group addressed this question multiple times throughout the study. As new experiences arose, they reflected on the impact as well as reconsidered impacts of earlier experiences. Programmatic components including the two courses (NOS Research and College Science Methods), teaching experiences, NOS research projects, and group support were reported to be main influences. Elements within these components that served as triggers for NOS developments are discussed here.

Graduate courses.

Both the NOS Research course and the College Science Methods course reportedly influenced views of NOS, views of NOS teaching, and abilities to teach NOS. This finding alone is not a surprise, given the focus of the courses. However, the more intriguing findings stem from the graduate students' descriptions of learning components within and across the courses that they feel challenged them to consider personal NOS views as well as views of science teaching and learning. These elements include consistency of NOS message; opportunity/requirement to formalize NOS views; opportunities to evaluate NOS views relative to others', to readings, and to activities; requirement to plan NOS objectives and instruction in lesson plans; requirement to include NOS in lesson presentations; feedback from faculty and peers; observations and interviews of college science teaching/teachers; requirement of reflective discussions and writings. These elements were present within one or both courses experienced by the group.

NOS Research course. The group reported that the NOS research course had a positive impact with respect to enhancing NOS conceptual understanding and raising awareness of NOS teaching issues. Recall that four of the students began the course with beliefs in science as objective and product of a single scientific method. Robert describes his conceptual change:

> After my experience in the [NOS research course], my conception of what science is and what it is not changed completely. The knowledge I got out of the course took me to a completely different way of examining scientific claims. I came to understand and appreciate that scientific knowledge is tentative and there was never a mighty scientific method. I learned to appreciate that prior knowledge plays a big role in the observations scientists make. This makes science subjective and debatable. [Robert, final narrative]

Specific elements of the course were reportedly most influential: *NOS activities, group discussions, teaching observations, readings, and reflections*. The simple, non-threatening NOS activities that introduced the concepts were thought to be essential to providing common experiences. These experiences served as a basis for discussion about the more philosophical issues and personal controversies. Observing and reflecting on college science teaching (assigned observations for the course) raised awareness of how typical science teaching may misrepresent NOS. These experiences also provided context for group discussion.

> I really began to understand what was meant by NOS when we conducted observations of classroom teaching. I observed a course that I had formerly taught and felt constrained by the ideas of right and wrong answers or methodology. It was through this observation and subsequent interview with the instructor that I realized that we are told by others that science is strict and all-knowing, but we understand within ourselves that it is not…the conflict is there, not just in me, but in others and that conflict needs to be resolved. [Brandy, initial narrative]

College Science Methods course. The group reported that the methods course further advanced NOS conceptual understanding and had great impact on understanding of NOS teaching. Instruction modeled integration of NOS within science content and within various instructional strategies, including lecture, discussion, and laboratory techniques. Students were required to develop a course syllabus and unit lesson plans (comprised of at least five instructional sessions). They were required to include explicit NOS objectives, instruction, and assessments. Class sessions also focused on common misconceptions about NOS, facilitated by review of the research; and prompted frequent reflections on progressions in learning NOS.

Lesson presentations. Instruction modeled how to embed explicit NOS and science content. These lessons were accompanied by rationale of strategies for college science teaching. Discussion also focused on how NOS issues were attended in an explicit manner. Student groups developed and presented an inquiry-based lesson that included explicit NOS elements. Through presentation and discussion of these lessons, students were exposed to a variety of strategies and contexts for NOS teaching.

> A big impact was the methods course. From the NOS research course, I had memorized aspects without real understanding or application; The methods course required application and had more NOS activities and examples that helped clarify for me. I found it difficult to make connections with physics context, but lesson planning and feedback helped. Easiest for me was observation and inference and tentativeness. [Fang, final discussion]

Lesson planning. The participants reported that they valued lesson planning because the exercise demanded clear NOS understanding and pushed them to explicitly construct relevant objectives and instruction. The students realized that in order to teach NOS, they must have a good understanding of what NOS is. Thus, the lesson planning process challenged them to match their NOS ideas with the science content. They also came to realize that understanding NOS, although necessary, is insufficient to effectively and consistently incorporate NOS into science teaching. For some, this was a hard lesson to learn, as they tried to hold tight to the preconceptions that knowledge and implicit intentions would successfully translate into classroom practice. Through the required lesson planning, the students reported an increase in addressing NOS in their science teaching.

> During these courses there have been opportunities to incorporate aspects of NOS in the learning processes, most significant of which were the creating of lesson plans and presenting of micro-lessons which had NOS explicitly embedded. This helped me face and overcome the challenges involved in understanding and teaching NOS. I had to re-read some writings on NOS in order to properly use them. [George, final narrative]

> Under the pressure of the assignment, I started to think seriously on how to design a class. It took me some time and efforts on searching materials, examples, discussing with colleagues, but it was really a very good experience. After some hard work, some ideas came up. I started to understand where to put NOS in the science context; how to integrate both the NOS and subject knowledge to teach. This experience not only helped me learn how to teach NOS, but also improved my confidence in NOS teaching. [Fang, final narrative]

Peer interactions/sharing. The participants valued opportunities to share ideas and experiences in a safe and trusting environment. Experiencing different science lessons that attempted to embed NOS demonstrated a myriad of venues for explicit NOS teaching. Discussions about seized and missed opportunities within science lessons highlighted where and how various NOS aspects could be connected to science content and learning activities.

> The different peer teaching presentations from various disciplines and discussions helped me polish up and internalize further NOS. I could better see where and how NOS could be connected to the science content. [Robert, final discussion]

Classroom observations. Students were required to conduct six teaching observations (2 self, 2 peers, 2 other). These experiences brought a reality to why we placed so much focus on NOS and the images of NOS portrayed in typical college science classes. Observations and reflections pushed the students to focus on the how science is portrayed in real classrooms. For some, there was a challenge to set aside the typical science content and focus attention on NOS connections. Some students in the methods course were resistant to setting aside their content focus. Yet, the five students who had prior experience in the NOS research course seemed to be more successful in describing and analyzing NOS portrayals. The evidence for this statement stems from the primary researchers' access to student reflective writings completed for the course. Sample responses, however, are not available for the present paper.

Research

As a requirement of the NOS research course, the participants proposed research studies with a NOS focus. Brandy, Hang Hwa, and Robert completed their studies. The other two had problems recruiting participants and decided to delay their studies. Brandy, Hang Hwa, and Robert reported that the experience of studying others' views of NOS and NOS teaching practices impacted their own views of NOS, NOS teaching, and needs of teachers.

> I myself prepared some interview questions as I went through participants' reactions on questionnaires…I realized that I have no detailed ideas of views to make an analysis for my research. Therefore, I read references of NOS again because I want to get clearer framework for research analysis. [Hang Hwa, final narrative]

> I have been able to study the phenomenon of teaching aspects of NOS in the middle school. I gained great insights into the NOS views of middle school teachers. I also come to appreciate that teachers do not differentiate clearly by inquiry and teaching NOS. Teachers run short of the pedagogical content knowledge in as far as NOS teaching is concerned. This makes them unable to plan to teach NOS; those who try, they do it implicitly. [Robert, final narrative]

Teaching experiences

All five were teaching in the undergraduate science program for elementary education (Table 1) as part of their assistantships. As discussed above, they all reported trying to embed NOS within their instruction, and had various levels of success with various NOS aspects. They reported that these personal teaching experiences challenged their NOS views and teaching orientations. Initial teaching attempts were more difficult than expected. As George stated, "I thought it would be fairly easy, but it wasn't. I had to explicitly plan to teach it." Hang Hwa realized that to teach NOS, she needed to increase her comfort with her own NOS knowledge, "Planning required rereading of materials to be sure I know the content and planned appropriately." As she reflected on her NOS teaching and the impact on her own views, she realized the limitations of her own views.

> Discussions with students helped me to further reflect on my NOS views and effects of teaching attempts. I realized I wasn't being explicit enough. Students had some problems

> with understanding that I need to address. This made me further to understand NOS. Memorization is not good enough for teaching it. [Hang Hwa, final discussion]

The importance of planning became evident through the process of teaching attempts. They all reported that, especially initially, they would forget to make NOS connections unless they planned explicitly to do so.

> If I didn't use it in my planning, I wouldn't think about it. I thought it would be fairly easy, but it wasn't. I had to explicitly plan to teach it. The methods course required objectives and instruction. I then tried to put it into my chemistry course. I have to plan for it. [George, final discussion]

DISCUSSION

Each of the graduate students in this study experienced a change in perspective. For four, the change was dramatic with respect to understanding NOS and the relevance of NOS to science teaching and learning. One student, Brandy, was less comfortable with the absolutist view of science teaching, yet she felt she was *supposed* to think this way. Her NOS views did not mesh with what she thought they were supposed to be, at least as far as teaching science. For Brandy, learning about NOS was somewhat of a relief. Her "change in perspective" was different from the others in that she already understood many of the concepts of NOS, but she felt that she was supposed to teach science in the more absolutist, value-free way in which she was taught. Finding out that there was a concept called "NOS" that fit with her already formed conceptions validated her prior feelings about how she *wanted* to teach science. Her "change in perspective" was more relative to her views of good science teaching. For the others, the "change in perspective" was with respect to NOS views *and* with respect to what constitutes good science teaching.

That each participant experienced personal transitions and growth is not surprising, given the consistent message; requirements for personal reflection, modeling, planning, and teaching; and on-going support. These influential elements are consistent with prior research on developing teachers' NOS views and practices (Abd-El-Khalick & Akerson, 2004; Hanuscin et al., 2006; Lederman, 2007). The finding that these five students were more successful (albeit anecdotally) in incorporating NOS into their instructional plans and teaching during the Methods course compared to those students who had not previously been introduced to NOS, further supports the need for repeated exposure. The notion that "one course is not enough" (Akerson et al., 2006; Lederman et al., 2001) reverberates from this study.

Utilizing *Internal* Commitments toward NOS Conceptual Development and Teaching Practice

External factors such as program requirements may have initiated change, but it is perhaps the internal factors and perspectives of these students that provide insights to sustaining progressions once the external pressures subsided. Abd-El-Khalick & Akerson (2004) describe "motivational factors" as they relate to preservice elementary teachers' perceptions of the importance of NOS. What influences teachers' internalization of NOS? Our study suggests personal commitments to science teaching and personal goals are important factors. Programmatic requirements provided external pressures and supports to learning and teaching NOS. It was, however, personal commitments that seemed to enable the students to internalize what they had learned and, moreover, to negotiate challenges. The results suggest that tapping into a teacher's commitments to improving science teaching and learning may be paramount to advancing past initial conceptual understanding of NOS as a concept toward a more meaningful embracement of NOS as important for all science learners. This study identified common experiences and personal elements that seemed to utilize and deepen existing commitments. It is important to note that these features are not mutually exclusive from each other or the aforementioned programmatic elements.

Learning in Social Contexts

Group activities from courses, teaching discussions, and informal discussions challenged NOS conceptions and provided peer support and feedback. Our findings suggest the act of talking with others who share common experiences and goals helped trigger conceptual development and sustain motivations. Formal and informal reflective discussions in a safe and trusting environment were venues to vent frustrations as well as share personal ideas, pose “what ifs” and compare views and experiences. Learning did not take place in isolation. Challenges were not unique to any one person, nor were commitments to becoming a better science teacher. This finding is supported by the work of Loving and Foster (2000), who examined how graduate students understand compatibility of science and religion. They report that peer sharing provides a “sense of relief from most who had struggled to find a position but gained from the experience” (p. 465). For the present study, sharing, comparing, evaluating, and re-evaluating continued throughout the 18 months, regardless of course or program assignments. Conversations in graduate student cubicles often involved reactions, challenges, and possibilities regarding NOS. That this level of group sharing took place, and was valued, reflects an internalized commitment to NOS.

Orientations and Critical Appraisal

Our results support reflection as an instrumental factor in facilitating graduate students’ transitions in conceptual knowledge and teaching orientations (Irez, 2006; Loving & Foster, 2000; Volkmann & Zgagacz, 2004). Our results further suggest that motivation to continuously improve one’s science teaching may be an instrumental factor in realizing effects of reflection. For these graduate students, conceptions of “good teaching” and orientations toward becoming “good teachers” may provide the internal motivation necessary to gain from reflective and metacognitive activities. This finding can perhaps be better understood based on the work of Volkmann and Zgagacx (2004), who find that NOS views can support certain teaching orientations, but there is also a need to explore professional identity. They discuss the interplay between teaching orientations and professional identity. Challenges to beliefs are necessary to modify teaching orientations. Our work provides an in-depth examination and personal account of five graduate students' challenging their NOS beliefs through continued reflection and action.

Reflection, however, did not come automatically. Course assignments, modeling, and scaffolding of reflection on experience seemed to facilitate a reflective perspective. Outside of coursework, reflection about others' teaching, personal teaching, and science-related encounters (e.g. readings, media, conversations) seemed to prompt further reconstruction of NOS ideas and needs for teaching. As external prompts waned, internal motivations may have taken front stage to sustain learning. Our results suggest that multiple exposures aided the processes. For example, the first time reading about NOS and reading primary NOS literature can be overwhelming when the concept is brand new. Several reported that rereading the literature was helpful to advance NOS conceptions and awareness of its applicability of NOS. HangHwa reported that about six months after the NOS research course, she reread the same literature in preparation for her teaching and research. She was better able to understand the literature at the later time. What was different the second time around? First, her reason for reading the material was different. Reason shifted from external (course requirement) to internal (prepare for teaching and independent research). Second, she had an idea about NOS as a concept. She was perhaps better prepared to critique and understand the descriptions and claims from the literature she was rereading. It could now make more sense to her, personally. It seems that she had internalized NOS as a concept of importance and utility, wanting to incorporate NOS into her own teaching. Similar shifts with understanding NOS literature were reported by Fang, Robert, and George.

<u>Self-Awareness</u>

Formal and informal discussions and reflective writings prompted the graduate students to assess their NOS views and teaching views. They became *critical appraisers* of themselves as well as their students. This theme of "self-awareness" emerged from the findings. The students utilized their self-awareness regarding personal views of NOS and requirements for successful learning and teaching. As a group, they realized the need to *plan for teaching* NOS in order to teach NOS. They realized the need to understand NOS and connections to their science content in order to plan for teaching NOS. They repeatedly claimed to critically appraise the adequacy of their own knowledge and abilities for that which is necessary for “good teaching.” The metacognitive perspective needed for such appraisal was evident from the beginning of the NOS research course. It is interesting that four of the five were initially “shocked,” as Fang described it, to discover they had never been exposed to NOS before, despite their extensive science backgrounds. Could such a realization serve as a springboard for conceptual change? Through initial readings, writings, and discussions that prompted comparison of personal views with advocated NOS perspectives, the graduate students began their journey of critical appraisal.

Awareness of and Concerns for Students

The graduate students expressed concerns for student learning and discussed student preconceptions regarding science. We saw this type of appraisal very early in the program when George and Robert wondered how children in Cameroon and Uganda would react to learning NOS. As the graduate students attempted to teach NOS in their undergraduate courses, they were aware that their students held many of the same misconceptions that they themselves had held. This awareness of students and recognition of student challenges seemed to integrate with awareness of the graduate students’ own learning progressions for NOS. The integration may have helped several of the graduate students understand student struggles.

> The engrained nature of [students] earlier views makes it more challenging for me. I feel my teaching has improved because I am able to explain certain issues in science to my students in a more appropriate and convincing manner. I also find my students getting less confused with some activities as they understand they can use different approaches, have different results, and feel they are doing science… My greatest frustration has been having some students still asking for “right answers” or “right procedures.” However, I think I am expecting a fast change when it was not that easy for me to understand some of these aspects

> of NOS. This consoles me and teaches me to be persistent but gentle in guiding students to an appreciation of NOS. [George, final narrative]

Science Teaching Efficacy

The cycle of trying to explicitly teach NOS, reflecting on attempts, trying again, reflecting, trying, reflecting, and so on….reportedly had a positive impact on the graduate students' self efficacy for NOS teaching and for science teaching in general. Initial frustrations were met with commitment to do better. Peer and faculty support provided a safety net to sustain motivation. Success served as a catalyst for further attempts. George described initial attempts to embed NOS with a lesson on atomic structure. He knew there were connections he could make. He planned. He taught. He reflected. He saw additional opportunities. He reports that now, he sees opportunities for embedding NOS in everything he teaches. Hang Hwa experienced small successes with her summer methods course. She brought those successes to her biology course. She reported feeling like a better teacher. Robert and George make similar claims. They feel their teaching, in general, has improved because of their perspective and inclusion of NOS connections in their classrooms. Course evaluations and teaching observations by faculty supervisors support their claims. Similar impacts on teaching efficacy have been described with elementary teachers (Akerson et al., 2006; Abd-El-Khalick & Akerson, 2004), secondary preservice teachers (Author et al., 2002), and undergraduate teaching assistants (Hanuscin et al., 2006).

Cultural Border Crossings

The novelty of NOS surprised four of the five graduate students. These four were international students, originating from four different non-Western countries. They reported learning science from within a "Western" perspective, consistent with absolutist promotions. NOS seemed a welcomed change to their prior perspectives. Their worldview (in as much as we can describe the participants' worldviews from self-report) seemed more compatible with NOS ideas promoted in the program. This is consistent with Abd-El-Khalick and Akerson's finding that preservice teachers who held worldviews compatible with NOS ideas were better positioned to advance their NOS understandings (2004). For the present study, the inclusion of NOS as a descriptor of the culture of science may have eased border crossing issues (Aikenhead & Jegede, 1999) seen between school science and life-worlds for these students.

Motivations for continued learning also stemmed from (1) future goals as science educators, and (2) potential impact of NOS as it relates to those goals. Being an international group, the students discussed possibilities of introducing NOS in their home countries. The students saw NOS as a means of easing border crossings for their future students, especially those from non-Western cultures. Aikenhead and Jegede (1999) described how students are required to transition from one culture to another in order to learn science. "To acquire the culture of science, students must travel from their everyday life-world to the world of science found in their science classroom. Students' flexibility, playfulness, and feelings of ease in the world of science will help determine the smoothness with which students cross the border into the culture of science (Aikenhead & Jegede, 1999, p. 274). Robert reflected on his prior view that science is exclusively "Western" and discussed the potential of NOS as an avenue for motivating, establishing, and maintaining science learners in Uganda. He has come to value the creativity and social and cultural aspects that he feels would be inspirational to African children. Likewise, George considered how he might raise awareness of NOS to learners in Cameroon as a science educator.

> I do not only see science now as this body of knowledge and processes which students have to know so as to pass exams, but also as a way of knowing. At this moment I cannot stop wondering if Cameroonian students are actually becoming scientifically literate and what effect this has on the society. This leaves me thinking about what can be done in bringing about a change in the teaching and learning of science in Cameroon. [George, initial narrative]

CONCLUSIONS AND IMPLICATIONS

These stories of personal reflection highlight challenges and influential factors in the preparation of science educators. The "change in perspective" experienced through this program was multifaceted. These future science educators demonstrated change relative to their NOS knowledge, NOS teaching, science teaching, and potential professional contributions within different cultural settings. They reported profound realization that, despite substantial science knowledge and experiences, they had not *really* thought about NOS before, or they had passively accepted the traditional view. Reflection on prior learning experiences and science practice in light of NOS readings and activities provided cognitive dissonance. These students were able to identify applications of NOS to address other issues in science learning that were already of concern to them (e.g. cultural perceptions and attitudes toward science). These metacognitive elements may be critical to breaking the cycle of "teach as you have been taught."

Seeing NOS as an integral component of science literacy seemed to be necessary for advancing conceptions and teaching skills without external pressures. We identified external and internal factors that are associated with these graduate students' learning and teaching of NOS. These factors are overlapping, yet there seems to be a necessary shift from relying primarily on external factors to drawing upon internal motivations to sustain momentum regarding a NOS focus. Figure one represents our interpretation of the relationship between external and internal motivating factors that influenced NOS conceptual and pedagogical developments in this study. External factors of course requirements initiated the process of learning and teaching about NOS. Initial successes in learning and teaching may lead to transformed conceptions of "good science teaching" to include NOS by tapping into personal and professional factors. For these graduate students, *continued* NOS conceptual and pedagogical developments seemed to be influenced by internal motivations associated with (1) Professional identities and goals: commitment to becoming better science teachers and science teacher educators, (2) Teaching orientations: values and perceptions of science teaching and learning, and (3) Personal identities and goals. There may be a complex relationship between the *relative* reliance on external and internal motivations and conceptual and instructional development, at any given time. The internal motivations are always there, but may shift in relative impact as perceptions about science teaching shift. Valuing NOS as a construct may enhance, or may contradict, a teacher's professional identity as a science teacher and scholar. The efficacy of this proposed model for other graduate and teacher education programs should be explored. Potential associations, prerequisites, exclusions, additions, and cultural influences need to be examined through future research.

------ Insert Figure 1 about here -----

What does it mean to be a science teacher? What science, how, and why should I teach my students? To internalize the importance of NOS, our study suggests that conceptions of NOS likely need to be compatible with a teacher's answer to these questions. Tsai (2002) reported this notion of "nested epistemologies" where teachers' conceptions of NOS may relate to their conceptions of science teaching and learning. Tsai suggests that "Changing teachers' beliefs of teaching and learning science may be a prerequisite of changing their beliefs about science, or vice versa (p. 780). This idea deserves additional exploration. Our study suggests that NOS needs be viewed as an ingrained part of the science curriculum, essential for scientific literacy, but, moreover, essential for motivating learners toward science. Examining NOS learning from perspectives of motivation theory, orientations, and identity may help us to understand deep internal factors that are facilitators or barriers to success.

Our results highlight the importance of consistency and repeated challenges toward learning NOS within the science education graduate program. Opportunities for critical discussion in a safe and trusting environment may facilitate reflection necessary for change (Loving & Foster, 2000; Smith & Scharmann, 2008; Tsai, 2002; Wlodarsky, 2005). The two courses and NOS research group kept NOS visible for these students. They could not just learn about it in a class and leave it behind. Four of the five admit they likely would have regressed to earlier teaching orientations had they not been pressed to keep thinking about it and practicing. Akerson et al. (2006) reported such digression among future elementary teachers. Consistent exposure and multiple challenges for examining existing NOS ideas and teaching practices are recommended for K-12 preservice teacher programs (Abd-El-Khalick & Akerson, 2004; Akerson et al., 2006; Lederman, 2007). We make the same recommendation for the preparation of science teacher educators. For science education graduate programs, we recommend consistent exposure, multiple challenges for reflection, and supported experiences in teaching NOS within science content contexts. The added challenge for these future science educators is developing proficiency to teach others how to teach NOS. Further research is clearly needed in all these areas.

The cultural diversity of the participants offers us a glimpse into the potential role of NOS as a bridge between life-world views and the culture of science. The non-Western graduate students embraced NOS as having significant potential to open the world of science to more students in their home countries. Does the inclusion of NOS change the culture of school science? Can the change be such that cultural border crossings become less hazardous or even *smooth* (Aikenhead & Jegede, 1999)? How does NOS affect students' "feelings of ease" with respect to the culture of science? Does NOS have the potential to make science accessible for learners across the globe? These are worthy questions for further study.

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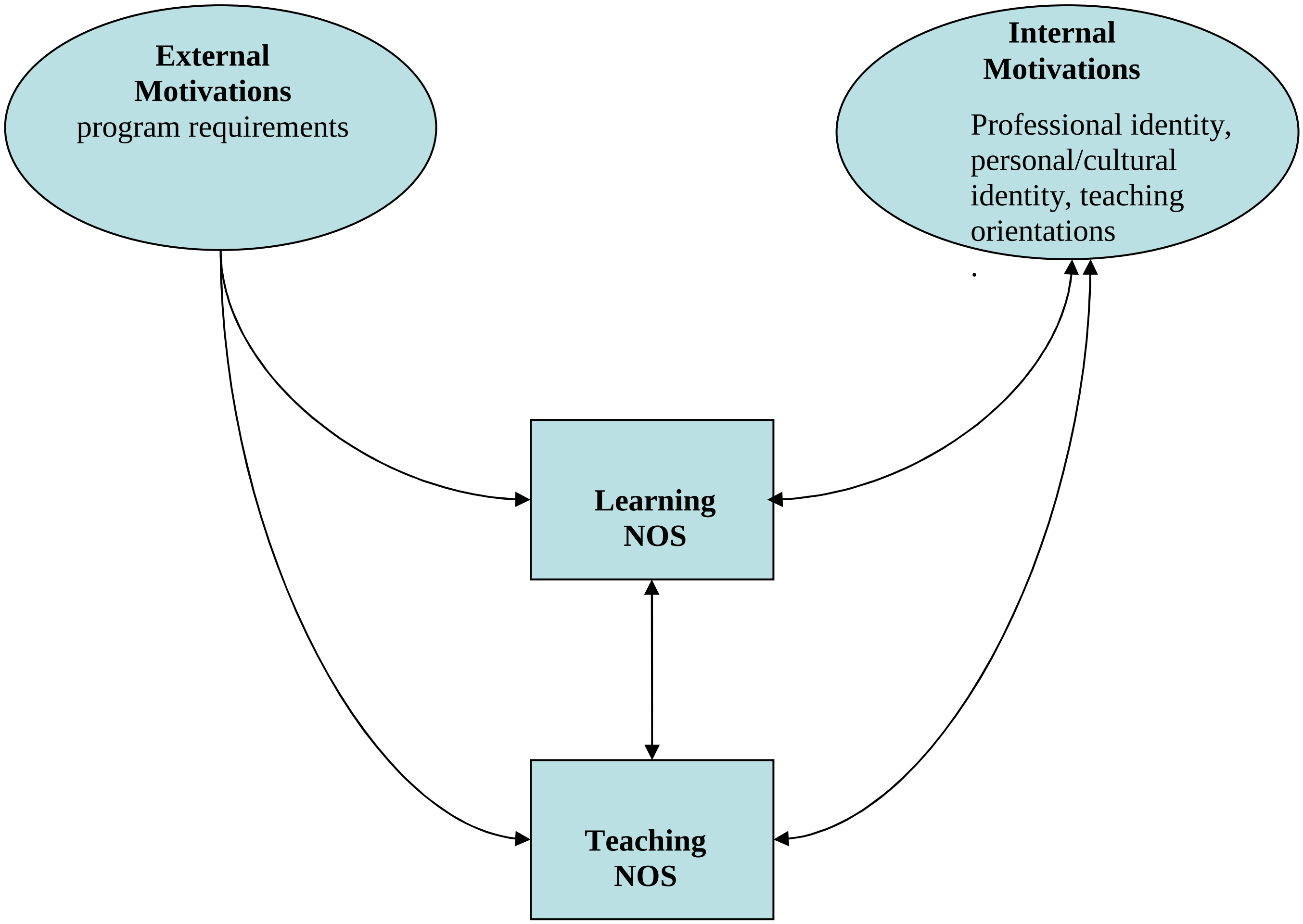

Figure 1: Interplay between internal and external motivation and the teaching and learning of NOS. Lines and arrows indicate direction of influence.

Table 1. Participant biographical information

	George	Hang Hwa	Robert	Fang	Brandy
Gender	Male	Female	Male	Female	Female
Degree seeking	PhD science education	PhD science education	MA science education	PhD science education	PhD science education
Home country (where educated and gained teaching experience)	Camaroon	Korea	Uganda	China	United States
Teaching experience	7 years teaching grades 6-12; Physical science and chemistry	5 years (4 Korea; 1 US) Science education: preservice elementary teachers; masters students; inservice workshops Biology: undergraduate non-majors; preservice elementary teachers; inservice elementary	8 years teaching community college level; Biology and science education	none	8 years teaching college level; biology, microbiology
Education Degrees/major/minor	S. Chemistry Graduate Diploma (Curriculum & Teaching Studies) M.S. Environmental Technology	B.S. Biology M.S. Biology Ph.D. Botany	B.Ed Biology	B.S. Engineering M.S. Higher Education	B.S. Ecology M.S. Biology
Science research experience	None	10 years botany and plant taxonomy	None	None	Mycorrhizal Fungi Nitrogen-fixers Plant Ecology
Prior experience with NOS & HPS (courses, reading, etc)	None	Brief reading within a course textbook; nothing explicit	Part of a prior course; nothing explicit	Part of a prior course; nothing explicit	HPS course; read Kuhn but book was not analyzed from a NOS perspective
Teaching assistantship (all courses are designed for elementary education majors)	Chemistry	Biology	Biology	Physics	Biology

Appendix

Initial Reflective Narrative prompts

1. Describe who you are, your educational and teaching background.
2. What were your initial assumptions beliefs, thoughts, and feelings about NOS?
3. What were your first reactions to learning about NOS?
4. What are your main experiences with NOS that stand out clearly to you?
5. Who were/are main people involved in your NOS experiences?
6. What have been your difficulties with NOS?
7. What moments have been significant to you concerning NOS learning?
8. What are you capable of doing now or can do differently regarding NOS? [what have you learned?]
9. What do you think you need to help you continue to move forward with NOS?
10. What are the implications of your experiences with NOS for you in terms of learning, teaching, and research?

Final Impact Statement [guideline prepared by primary researcher; based on analysis of initial narrative and group discussions]

Through metacognitive reflection, we want to describe developments in your learning about and orientations toward NOS teaching and research. We want to describe key turning points influential elements and challenges that you experienced.

1. How do you feel you have most changed regarding your views of NOS? How did you understand this aspect before? How do you understand it now? What do you feel had the most influence on developing your understanding?
2. Teaching science in the undergraduate program: What have you been able to do regarding NOS teaching? What aspects have been easiest? What aspects have been most difficult? How have students responded to NOS? How has your teaching experience impacted your views of NOS? Views of NOS teaching?
3. Research experience: Describe the NOS research you were able to conduct this past year. Describe the impacted of this experience on your views of NOS, NOS teaching, and NOS research.
4. Methods course: Describe the impacted of this course on your views of NOS, NOS teaching, and science teaching. What experiences do you feel influenced your views regarding NOS?
5. Describe any other experiences you have had that you feel impacted your understanding of NOS, NOS teaching, NOS learning, and NOS research.