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Explicitly Targeting Pre-service Teacher Scientific Reasoning Abilities and Understanding of Nature of Science through an Introductory Science Course

Abstract

Development of a scientifically literate citizenry has become a national focus and highlights the need for K-12 students to develop a solid foundation of scientific reasoning abilities and an understanding of nature of science, along with appropriate content knowledge. This implies that teachers must also be competent in these areas; but assessment of students in our teacher preparation program indicated they were not developing necessary scientific reasoning abilities or a sophisticated understanding of nature of science. As a result, explicit scientific reasoning-oriented training modules and reflective nature of science activities were integrated into the program's science foundations course. Significant gains were observed in each. These findings highlight the need and motivation for teacher preparation programs to incorporate coursework that promotes the development of scientific reasoning and a more contemporary view of the nature of science. In addition, this study provides a framework for the modification of existing teacher preparation courses to meet these needs.

Introduction

Reports from large-scale international studies of science and mathematics education, such as TIMSS and PISA, continually rank U.S. students behind many other nations. In response, the U.S. has increased its emphasis on the implementation of a more extensive curriculum in K-12 education in science, technology, engineering, and mathematics (STEM). For example, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (2012), the basis for the first public draft of the Next Generation Science Standards (NGSS), recently suggested reforms that view science education through three dimensions: scientific practices, crosscutting concepts, and core ideas. The latter two compose the content of science, while the first dimension focuses on how scientists come to develop scientific knowledge. These practices include asking questions, developing and using models, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, constructing explanations, engaging in argument from evidence, and obtaining, evaluating, and communicating information. One important component that runs through these practices is an understanding of nature of science, which refers to the values and beliefs inherent to scientific knowledge and its development (Lederman, 1992; 2007). In addition to the broader aspects of scientific knowledge development, individuals must also grasp finer scientific and mathematical reasoning abilities in order to enact these practices. When taken together, nature of science (NOS) understanding and scientific reasoning (SR) abilities include the thinking and reasoning involved in inquiry that supports the formation and modification of concepts and theories about the natural and social world (Zimmerman, 2005).

Keywords: scientific reasoning, nature of science, teacher preparation, college

Understanding nature of science.

Although a single description for NOS does not exist in the research literature, McComas, Clough, and Almarzoa (1998) reported on commonalities between eight international science education standards documents. These include scientific knowledge as empirically-based, tentative, creative, theory-laden, and socially/culturally embedded. Abd-El-Khalick, Bell, and Lederman (1998) further suggest the inclusion of the distinctions between observation and inference as another important aspect of NOS. Tsai (1999) adds yet another dimension involving the role of social negotiation. These aspects of NOS provide guidance for the implementation and interpretation of scientific practices.

Research has shown that students do not typically acquire a sophisticated understanding of NOS and that this development can be difficult to achieve (Lederman, 1992; Lederman & O'Mally, 1990; Tamir & Zohar, 1991). Unfortunately, teacher candidates have been found to be severely lacking in these areas as well (Abd-El-Khalick et al., 1998; Palmquist & Finley, 1997). This is particularly problematic in light of *A Framework for K-12 Science Education* as teachers with more sophisticated views of NOS have been found to be more likely to implement problem-based learning or student-led investigations (Keys & Bryan, 2001; Trumbull, Scarano, & Bonney, 2006), as well as include appropriate NOS-related activities in class instruction (Schwartz & Lederman, 2002). Others have shown that instructors' conceptions of NOS influence their approaches to teaching science particularly in terms of selecting more inquiry-based curriculum (Lederman, 2007; Lotter, Harwood, & Bonner 2007; Southerland, Gess-Newsome, & Johnston, 2003; Tsai, 2002). This implies that teacher preparation programs must emphasize the development of a sophisticated view of NOS amongst teacher candidates along with an understanding of the instructional practices that develop these abilities in students. Unfortunately, most elementary teacher preparation programs lack a course on NOS and do not place any emphasis on the topic outside of a methods course (Backus & Thompson, 2006).

Scientific reasoning abilities.

Scientific reasoning (SR) can be understood as a set of abilities necessary in carrying out scientific practices – abilities both related to the collection and analysis of evidence, as well as those used to generate a cohesive evidence-based argument. For the purpose of this study, we focused on the former set of abilities. To collect appropriate scientific data, one must be able to design a study with pertinent hypotheses and controlled variables. Collected data must then be evaluated to identify patterns using proportional reasoning, probabilistic reasoning, and/or correlational thinking (Lawson, 1982). These abilities are emphasized in *A Framework for K-12 Science Education* as strong scientific practices through which students ask and answer questions, use computational thinking to analyze data, and evaluate conclusions that address these questions.

Strong SR abilities have been found to positively correlate with course achievement (Cavallo, Rozman, Blickenstaff, & Walker, 2003; Johnson & Lawson, 1998), improvement on concept tests (Coletta & Phillips, 2005; She & Liao 2010), and success on transfer SR questions (Ates & Cataloglu, 2007; Jensen & Lawson, 2011). However, Lawson (1992), states that as many as 50% of students in freshmen-level college biology do not engage in higher order SR. Work centered on the characterization and advancement of these particular abilities has demonstrated similar findings. For example, studies on student abilities related to control of variables have illustrated success of undergraduate students when comparing trials in which the variables are simple and straightforward. However, these same students display difficulties in more complex scenarios, especially in recognizing variables that should be held constant for valid comparisons (Boudreaux, Shaffer, Heron & McDermott, 2008; Shadmi, 1981). When investigating hypothesis-testing abilities of preservice teachers, Lawson (2002) found that context influenced success in hypothesis testing, with observable causes posing fewer difficulties than unobservable causes. Lawson also noted that students have confusion in distinguishing hypotheses, predictions, results, and conclusions. These results imply that students need dedicated instruction in these SR abilities.

Developing NOS understanding and SR abilities.

The relationship between instructional methods and the development of student understanding of NOS and SR abilities has been widely studied (Abd-El-Khalick & Lederman, 2000; Benford & Lawson, 2001; Zimmerman, 2005), particularly in establishing the educational outcomes between explicit and implicit instructional approaches. Although it is often expected that the consistent and rigorous content learning of the traditional classroom will help develop students' general reasoning abilities, we have previously shown that the content-rich style of physics education has little impact on the development of such (Bao et al., 2009). An explicit instructional approach makes a deliberate attempt to focus the learners' attention on specific aspects of NOS and SR abilities during classroom activities, discussion, and assessment. This instructional approach places understanding of these abilities as a central learning outcome, with activities and assessments developed specifically for this purpose, rather than as an auxiliary learning outcome. Multiple studies provide evidence for the effectiveness of this instructional approach (Abd-El-Khalick & Lederman 2000; Khishfe & Abd-El-Khalick, 2002; Ross, 1988). On the other hand, an implicit instructional approach asserts that an understanding of NOS and SR abilities results from the actual engagement of students in inquiry-based activities without a specific focus on instruction for these abilities. Although it is well-documented that inquiry-based learning promotes SR abilities (Adamson et al., 2003; Jensen & Lawson, 2011), research results indicate that implicit instructional approaches using inquiry do not effectively develop student understanding of NOS (Sandoval & Morrison, 2003; Schwartz, Lederman, & Thompson, 2001). Finally, reformed instruction has been shown to have secondary effects in which inservice teachers who were taught using reformed methods are more likely to use reformed teaching, leading to increases in student SR abilities (Adamson et al., 2003).

Purpose of research.

The demonstrated research-based links between teacher understanding of NOS and abilities in SR with reformed teaching practices led us to investigate the effectiveness of our own teacher preparation program in these two critical areas. Prior to this study we administered Lawson's Classroom Test of Scientific Reasoning (LCTSR) (Lawson, 1978; Lawson et al., 2000) to 106 preservice teachers entering our middle childhood education program as well as 50 preservice teachers exiting the program who had chosen science as one of their teaching concentrations. The LCTSR includes 6 distinct abilities: conservation of mass and volume, proportional reasoning, identify and control variables, probabilistic reasoning, correlational reasoning, and hypothesis testing. None of the entering students had completed any of their science course requirements when the test was administered, but those exiting the program had taken as many as 10 science content, inquiry-based courses. Surprisingly, the LCTSR averages for the entering and exiting cohorts were not significantly different (independent samples t-test, $p = 0.178$; TOST test of equivalency, $t_1=2.66$, $t_2=5.26$, $t_{\alpha=0.10} =1.29$, $df =159$) with a 62% and 66% average, respectively. In addition, student understanding of NOS was measured for both groups of students using a survey piloted by the authors of this paper. The survey contained 21

Likert-scale statements, based on the key characteristics of NOS as investigated in science education research that ranged from strongly agree to strongly disagree. Sample survey statements included "scientific knowledge may be affected by personal bias" and "the method of scientific inquiry changes depending on the situation being investigated." A team of science education experts reviewed the survey for face validity and determined preferred responses. Reliability was determined by a Chronbach's alpha (α = 0.60). Items were reversed scored, as needed, and all individual survey responses were summed such that total scores closest to 105 represented more sophisticated views of NOS. No significant differences in student responses were observed using an independent samples t-test (p = 0.607; TOST test of equivalency, t_1=9.95, t_2=10.91, $t_{\alpha=0.10}$ =1.29, df =159) with both cohorts mean scores at 73.4 and 74.1, respectively. The results of these assessments are disturbing in that our science concentration candidates do not enter or exit our program with high levels of SR abilities or sophisticated views of NOS.

As a result of this finding, the curriculum was replaced in our *Foundations in Scientific Literacy and Problem Solving* course, the first science course taken by all of our early and middle childhood majors. This course was originally designed to address science process and math abilities through the topic of properties of matter, but the format of instruction was implicit in nature. The new curriculum was adopted from another course, *Scientific Thought and Method*, developed by the authors of this paper as part of an NSF STEP grant (DUE 0622466), which focused on developing student scientific reasoning and math abilities to improve retention of incoming STEM majors (Koenig, Schen, Edwards, & Bao, 2012). This latter course involves an explicit practices-based instructional approach. Therefore, the research aims for this study were to determine whether the adopted curriculum could be implemented with preservice teachers to (1) improve their scientific reasoning abilities and (2) positively impact their understanding of NOS.

Method

Participants.

This study was conducted with preservice early (grades K-3) and middle childhood (grades 4-9) teachers enrolled in a *Foundations in Scientific Literacy and Problem Solving* course at a large public university in the Midwest. All students enrolled in one of four sections of the course offered during 2010-11 agreed to participate in the study. All sections of the course (n=86) used the same course manual (Koenig, 2012) and were taught by three different science education faculty. These students consisted of 74 female (86%) and 12 male (14%) students. Sixty-two percent were enrolled in the Early Childhood Education (grades K-3) program with the remaining 38% in the Middle Childhood Education (grades 4-9) program. In terms of prior science coursework, 98% took at least one course in high school biology, 93% took at least one course in high school chemistry, and 30% completed a high school physics course. Thirteen percent had one college science course prior to this study, most often a course for non-majors. The majority of students were sophomores (47%), followed by juniors (26%), freshmen (21%), and seniors (6%).

Context.

The *Foundations in Scientific Literacy and Problem Solving* course is typically the first science course taken by all early and middle childhood education majors in our university. The 10-week course meets twice a week for 2.5 hours each. Class size is limited to 24 students. The course is comprised of integrated lecture and lab and students work through the same workbook/text (Koenig, 2012). The curriculum focuses on student development of scientific practices and a sophisticated understanding of NOS. It is based on the Karplus learning cycle (Karplus, 1964) and models best teaching practices. Although each class may begin with a brief lecture to present or review topics necessary for the day's activities, the majority of class time involves students working cooperatively through activities in the text. The instructor frequently interacts with students during established checkpoints as a means of assessing student learning and guiding students to correct understanding. Other interactions involve the instructor facilitating class discussions in which students share data or ideas with one another as directed by the course activities. The implementation of explicit instruction is primarily through reflection as students complete activities before being guided to recognize the application of appropriate NOS or SR aspects to specific science contexts (Dickinson, Abd-El-Khalick & Lederman, 1999).

Explicit NOS instruction.

As part of this study, a series of activities were implemented that utilize explicit and reflective NOS instruction. The elements of NOS targeted in the course include scientific knowledge as empirically-based (testable, based on evidence), tentative and changing, subjective (including influences of personal bias, theories, and culture), dependent on social negotiation, and invented and creative.

Students are initially provided with full descriptions of the tenets of NOS targeted in the course. Students then engage in a series of activities in which they reflect upon and apply these tenets. Table 1 highlights some of these introductory activities, which have been adapted from the work of Lederman and Abd-El-Khalick (1998) to include a context that embeds them within scientific practice. These introductory activities comprise two class periods, roughly 5 hours total. Throughout the remainder of the course, students continue to reflect upon and further develop their understanding of NOS through discussion questions at the end of each scientific investigation.

Explicit SR abilities instruction.

The focus of the curriculum is to engage students in all aspects of scientific practice including hypothesis writing, experimental design, data collection and analysis, and argumentation while addressing specific underlying SR and math abilities. The specific SR abilities

Table 1: Highlighted Activities that Explicitly Support NOS Instruction

Main NOS Tenets Demonstrated	Activity Description
Scientific knowledge is partly the product of human inference, imagination, creativity, and social negotiation.	Each student is provided with a fossil fragment from the same organism. They are asked to draw the actual fossil fragment in one color and an inferred drawing of what may have been the complete organism in another color. Students also extrapolate the habitat, diet, behavior, and other characteristics of the organisms. A class discussion follows regarding how students' made their inferences about the complete organism. Students learn that scientists may differ in conclusions derived from the same evidence and a discussion of how these differences are settled through social negotiation follows.
Scientific knowledge is partly the product of subjectivity, as well as social and cultural context.	Students are provided a short paragraph that describes the steps in doing laundry. However, key words have been omitted, such as clothing or detergent, so the paragraph makes little sense to the students. They are asked to interpret what the text means to them and then share their ideas with the class. Students learn the prior knowledge, experiences, and expectations that scientists hold help them make sense of data and in turn may lead to different interpretations of the same evidence.
All targeted NOS tenets are emphasized in this activity.	Each group of students is provided with an identical set of 4 mystery boxes (e.g. Obscertainers™). Inside each opaque box is a plastic shape cut-out that a small steel ball rolls around or within. Students use their senses to determine the shape cut-out inside each box and reach a consensus within their group. Group ideas are then shared with the entire class in an attempt to reach a broad consensus of the shape inside each box. During this class discussion students may retest the boxes and change their ideas based on additional evidence. Upon completion of the activity, students are not allowed to open the boxes to "check their answers" to model the work of scientists.
Various NOS tenets depending on article selected by instructor.	Homework assignments throughout the duration of the course require students to read articles, often from the New York Times™, and clearly describe how elements of NOS are exemplified in the article. This activity also shows up on course exams as a means of assessing student understanding of NOS.

targeted in the course include probabilistic thinking, proportional reasoning, identification and control of variables, correlational reasoning, and hypothesis testing. The method of instruction in developing these abilities mirrors that for developing student understanding of NOS. That is, explicit introductory activities are provided for each targeted SR ability (Table 2). This includes short introductions by the instructor and then students practice the ability within provided science contexts while actively reflecting on how the activities employ that ability. Carefully designed homework questions provide additional instructional support. Subsequent activities, embedded in a variety of science contexts, are woven throughout the remainder of the course in an effort to provide further practice and promote transferability. Many of the activities involve simple contexts, which enable students to focus on targeted abilities and practices of science rather than become distracted by complex scenarios and science content. A more thorough description of the scientific investigation elements of the course along with specific course activities can be found elsewhere (Koenig, Schen, Edwards, & Bao, 2012).

Connecting NOS and SR abilities. Similar to the work of Khishfe and Abd-El-Khalick (2002), we sought to emphasize awareness of certain NOS aspects and SR abilities by having students reflect on course activities from within a framework comprised of those targeted areas. As an example, after each investigation, groups present their data

Table 2: Highlighted Activities that Explicitly Support SR Abilities Instruction

Main SR Abilities Demonstrated	Introductory Activity Description
Probabilistic Thinking	Students create histograms for observed frequencies of the sums of 100 rolls of a pair of dice. Students then compare their individual histograms with a histogram of compiled class data and later a histogram based on calculated probabilities. This activity is the springboard for future discussions on how probabilistic thinking, such as that related to sample size, plays a role in the development of scientific knowledge.
Proportional Reasoning	Students are introduced to the concept of proportional reasoning through the conversion of measurement units. As part of this activity, students measure their lab table using both their hands and rulers, relating the two methods and resulting measurements while discussing the usefulness of each. Later students identify proportional relationships through graphing activities associated with actual scientific investigations and use this reasoning to develop mathematical models.
Identification and Control of Variables	Students are first provided with multiple sets of data and thought experiments in the form of text, graphs, and tables from which they practice identifying the independent and dependent variables along with the hypothesis being tested. Students later apply this ability when designing their own experiments.
Hypothesis Testing	Students are introduced to Lawson's "if-and-then" template (Lawson, 1995) as a method for organizing experimental designs. They practice using the template through multiple thought exercises that also requires them to reason out logical outcomes from their hypotheses. Eventually students design their own scientific investigation using this template as a guide and after each investigation students present their findings to the class for peer review.
Correlational Reasoning	Students are introduced to the idea that variables can be positively or negative correlated, or have no correlation at all. Students practice this idea through thought experiments and later apply this reasoning at the end of each investigation conducted in class. For example, in one investigation students collect data to explore the relationship between rubber band stretch length and mass hung. The data is then graphed to determine the type of correlation between the variables.

and claims to the class through the use of whiteboards. Students learn to question each other and evaluate choice of hypotheses, experimental designs, and claims made. Students become critical reviewers through these discussions, and the instructor focuses student attention on the role of NOS as groups work towards constructing valid evidence-based scientific claims. For example, the process of students reflecting on each group's data and conclusions models the social negotiations involved in the development of knowledge within a scientific community. If results within the class are consistent and lend themselves to the development of a common class theory, the instructor directs class discussion in this direction. If not, the instructor leads students to discuss reasons why a common theory is not possible based on the combined findings, and what investigations could follow to reach possible consensus. In either case, when writing individual lab reports, students must cite the relevant data and claims of other groups to support or refute their own findings. These reflective discussions on NOS and SR abilities become more involved as the scientific investigations become more open-ended and complex. Many informal, unplanned opportunities for explicit NOS and SR abilities instruction also occur during class sessions due to the nature of the course.

Data collection and analysis.

Assessment of NOS understanding.

In order to assess student understanding of NOS, we chose an instrument developed and validated by Tsai and Liu (2005) as the authors suggest that an important use of the instrument is to evaluate the impact of science instruction on student epistemological views toward science. The 19 question 5-point Likert-scale survey assesses five dimensions of NOS including social negotiation, invented and creative nature, theory-laden exploration (subjectivity), cultural impacts, and the changing and tentative feature of science. Students respond to individual statements with strongly disagree, disagree, neutral, agree, or strongly agree. The complete survey and a detailed discussion of its validity and reliability can be found in Tsai and Liu (2005).

Students in the foundations course were given the assessment on the first day of class prior to any course activities and then given the same assessment during the final exam period eleven weeks later. Student responses were given a score of 1 to 5 based on the five possible responses on the Likert survey. Items were reversed scored, as needed, such that a score of 5 represented the more sophisticated view of NOS for each statement. Scores were summed for each of the five dimensions of NOS for each student on both the pre- and post-assessments. An examination of skewness and kurtosis z-scores indicate all data demonstrated normality ($p > 0.05$). A paired t-test was conducted for each of the five NOS dimensions as well as the total score to determine if significant changes were made (all compared variances were homogeneous). In addition, students were asked to identify and discuss instances of targeted NOS aspects as part of their first two exams. These answers were evaluated for common and persistent misconceptions regarding the identification and application of those aspects.

Assessment of SR abilities.

To assess SR abilities, we opted to modify the LCTSR for our use by removing questions that were not relevant to our course (conservation of mass/volume), along with some of the secondary reasoning questions. We replaced these questions with ones that expanded the question sets for the ability domains targeted in the course. This allowed us to assess students with a greater amount and variety of questions in the five SR aspects targeted in the course. To this end, we identified additional questions assessing these SR abilities from the multiple forms of the Biology Attitudes, Abilities, and Knowledge Survey and the Science Attitudes, Abilities, and Knowledge Survey (validated by Adamson et al., 2003).

The modified test (MLCTSR) was first piloted as a pre- and post-test in five sections (n=127) of another course, *Scientific Thought and Method*. This course was selected because it utilizes the same curriculum as the foundations course, save a greater focus on applications of the curriculum to future science major courses, and serves students at a similar point in their college curriculum. The pilot MLCTSR data was compared to data from students in six prior offerings of the same course (n = 152) who completed the original LCTSR as both a pre and post-test. Using an independent samples t-test, no statistical difference was found in pre-test total scores ($p = 0.257$; TOST test of equivalency, $t_1=6.03$, $t_2=3.77$, $t_{\alpha=0.10}=1.28$, $df=277$) or post-test total scores ($p = 0.787$; TOST test of equivalency, $t_1=4.79$, $t_2=5.43$, $t_{\alpha=0.10}=1.28$, $df=277$). The Cronbach's alpha of the pilot MLCTSR was found to be acceptable at $\alpha_{pre\text{-}test} = 0.747$ and $\alpha_{post\text{-}test} = 0.735$. Because our goal was to identify a valid and reliable question set that more directly assessed the SR abilities targeted in the foundations course, these findings indicated that the MLCTSR was appropriate for our assessment needs in this study.

Students in the foundations course were given the MLCTSR assessment the first week, prior to any related class activities, and then given the same assessment during the final exam period eleven weeks later. Student responses were not counted for a grade in the course. In scoring the MLCTSR, each correct answer was given one point and totaled. A paired t-test was conducted for each of the five SR abilities as well as the total score to determine if significant changes were evident (all compared variances were homogeneous). An examination of skewness and kurtosis z-scores indicate all data demonstrated normality ($p > 0.05$).

Findings

Assessment of NOS understanding.

In the 4 offerings of the foundations course, 84 students completed both the pre- and post- assessments. Results of the paired t-tests for each of the five NOS dimensions are shown in Table 3.

Each question was reversed scored, as needed, such that the highest possible score within each dimension was the number of questions within that domain multiplied by 5. The reliability of each administration was similar to those reported by Tsai and Liu (2005) with Cronbach's alphas of $\alpha_{pre\text{-}test} = 0.635$ and $\alpha_{post\text{-}test} = 0.747$.

Our findings demonstrate a significant shift toward more sophistication in students' understanding of the NOS tenets including social negotiation, creativity, and tentativeness of science with moderate to large effect sizes. Student understanding of NOS tenets associated with theory-laden and cultural impacts also improved, although not significantly. These results are not completely unexpected. The aspects that demonstrated significant gains were examined by the students on a regular basis in the course and consequently reinforced in a variety of experiences. Although the concept of subjectivity in science was also regularly discussed, it was addressed in relation to the impact of personal biases, beliefs, and previous experiences of scientists engaged in research. The survey questions, on the other hand, focused on particularities related to the influence of theories or culture on scientific conclusions, and as a result, students may have not been able to apply their general knowledge of subjectivity in science to these areas.

Looking at the total survey scores, there is a significant positive shift with an overall gain of 5.9% in total score and an average post-score of 80.6%. Gains such as these are similar to what others have observed when using explicit approaches to improving inservice and preservice science teachers' views of NOS (Abd-El-Khalick & Lederman, 2000). In addition, the standard deviations either remained relatively similar or decreased from pre to post-test for all tenets except theory-laden, indicating a more uniform understanding of NOS among the students by the end of the course.

Because the Tsai survey did not contain statements for all targeted aspects of NOS targeted, the first and second course exams were explored for common misconceptions exposed by open-ended questions. On the first exam, students were given an article from the *New York Times*™ (Rabin, 2008) and asked to identify and describe how each aspect of NOS was demonstrated in the article. The chosen article discussed the use of fish oil therapy to improve children's attention and focus, with evidence and conclusions provided by parents and doctors. On the second exam, students were asked to describe how their own experiences during a mealworm behavior investigation in class demonstrated each aspect of NOS. Although students did well on both exam questions, their understanding noticeably improved from the first to the second exam. A common problem on the first exam was that students tended to use the vernacular definitions of NOS aspects instead of the scientific ones, and this improved on the second exam.

In reviewing the exam questions in more detail, we focused on two tenets of NOS not included on the Tsai survey: empirically-based (testable, based on evidence) and subjective (as related to influences of personal bias). For empirically-based, all students were able to correctly apply this NOS tenet on both exams. However, responses were not complete as on the first exam 27% did not mention the necessity of observations as evidence and 30% did not mention the need for testing. The results were similar on the second exam. Due to the open-ended nature of the exam questions, it is unclear if the fact that students focused on one or the other implies they do not fully understand this tenet of NOS, but we are encouraged that all students recognized the significance of at least one of these. For subjectivity, correct student responses on both exams (88% and 82% respectively) demonstrated they understood this NOS tenet in terms of how it was explored in the course; i.e. the effect of personal bias or beliefs of the researcher. Although the Tsai survey subscales for subjectivity, found within statements for theory-laden and cultural aspects of science, did not demonstrate significant student improvement, the exam findings illustrate that students were able to grasp part of the role subjectivity plays in constructing scientific knowledge. Interestingly, the context within which each exam question was based, i.e. reflecting on a study reported in the research literature versus their own investigation, appeared to influence how students applied their NOS understanding. Students with misconceptions in this aspect saw it more as a characteristic of weak science which was highlighted by the increase in misconceptions on the

Table 3: Comparison of Pre and Post-Test NOS Scores

NOS Domain	Highest Possible		Mean	SD	p	Effect size
Total	95	Pre-test	71.02	5.24	0.000*	0.96
		Post-test	76.58	6.35		
Social Negotiation	30	Pre-test	23.12	2.27	0.000*	0.54
		Post-test	24.38	2.37		
Inventive and Creative	20	Pre-test	13.62	2.28	0.000*	1.00
		Post-test	15.86	2.20		
Theory-Laden	15	Pre-test	11.48	1.27	0.086	-
		Post-test	11.82	1.73		
Cultural Impacts	15	Pre-test	11.68	1.76	0.071	-
		Post-test	12.04	1.70		
Tentative and Changing	15	Pre-test	11.13	1.50	0.000*	0.93
		Post-test	12.49	1.41		

Note: A paired t-test was used for a sample of 84 students. As five dimensions and the total were tested, a Bonferonni-corrected a = 0.008 was used to test significance. A * indicates statistical significance.

Table 4: Comparison of Pre and Post-test SR Abilities Scores

SR Ability	Highest Possible		Mean	SD	p	Effect size
Total	24	Pre-test	13.51	3.88	0.000*	0.43
		Post-test	15.15	3.76		
Proportional Reasoning	5	Pre-test	2.74	1.38	0.000*	0.42
		Post-test	3.34	1.49		
Control of Variables	7	Pre-test	3.77	1.68	0.003*	0.33
		Post-test	4.28	1.41		
Probabilistic Reasoning	5	Pre-test	1.63	0.98	0.007*	0.36
		Post-test	1.94	0.75		
Correlational Reasoning	4	Pre-test	2.74	1.12	0.732	-
		Post-test	2.69	1.19		
Hypothesis Testing	3	Pre-test	2.63	0.94	0.044	-
		Post-test	2.90	1.06		

Note: A paired t-test was used for n = 87. As five domains and the total were tested, a Bonferonni-corrected a = 0.008 was used to test significance. A * indicates statistical significance.

second exam. Here students described a lack of confidence in their own experimental conclusions as only "their opinion" instead of a reasoned conclusion based on evidence. These results, coupled with those from the Tsai survey, indicate that this is an area that remains difficult for students to apply correctly in multiple contexts.

Assessment of SR abilities.

Of the 95 students enrolled, 87 completed both the pre- and post- assessments for SR abilities. Results of the paired t-tests for each of the five SR abilities are shown in Table 4. Each question was scored as either correct or incorrect, for a total possible score of 24. The reliability of each MLCTSR administration was determined by Cronbach's alpha as $\alpha_{\text{pre-test}} = 0.706$ and $\alpha_{\text{post-test}} = 0.705$.

The results of Table 4 demonstrate positive shifts in SR abilities with moderate effect sizes. Statistically significant improvements in total score, proportional reasoning, control of variables, and probabilistic reasoning were found. Hypothesis testing, although not a statistically significant improvement when using a Bonferroni-corrected alpha, also demonstrated improvement. As expected, those abilities that were targeted early on in the course and subsequently addressed more often in a variety of contexts and activities demonstrated greater improvement.

Conclusion and Future Work

The curriculum implemented in the *Foundations in Scientific Literacy and Problem Solving* course had a significant impact on students' overall scientific reasoning ability and understanding of NOS. Although statistically significant increases were not observed in all targeted SR abilities and the candidates did not shift to the most sophisticated view of NOS, these results demonstrate that explicit instruction in the form of reflective and targeted instruction in scientific reasoning can improve such abilities within a single comprehensive course. This is noteworthy in light of the poor test results obtained from candidates who had completed ten of the science inquiry-based courses in our teacher preparation program. In addition, our findings support the research literature that indicates SR abilities and understanding of NOS can be better targeted within inquiry-based courses that explicitly focus on reasoning training and include substantial and repeated practice within diverse science contexts (e.g. Abd-El-Khalick & Lederman, 2000; Ross, 1988).

Our results suggest that additional time and dedication may further develop our students' SR abilities and NOS understanding beyond this course. As a result, work is underway to both improve the foundations course in areas that lacked significant improvement, as well as develop and integrate relevant NOS-oriented and SR-targeted instruction into all subsequent subject-specific science courses in our teacher preparation program. This is critical in light of *The Framework for K-12 Science Education* which promotes student understanding of the enterprise of science as a whole; that is, in which students develop the abilities and knowledge of the *practices* and the science concepts that are foundational both within and across the specific disciplines. We believe that through repeated and scaffolded exposure to aspects of NOS and SR abilities in subsequent science courses that this will promote the transferability of these abilities and further studies will follow.

The findings of this study are also important in regards to concerns raised over the recent draft of the Next Generation Science Standards (NGSS). NSTA (2012) issued a statement indicating its' most serious and profound concern with the NGSS is the explicit omission of nature of science. The foundations course in our study not only explicitly addresses NOS early on, but promotes student reflection and discussion of aspects of NOS as related to each scientific investigation within the course. These activities also model for the teacher candidates how an understanding of NOS can be taught. A secondary concern expressed by NSTA is the teacher expertise necessary for students to achieve particular standards in the NGSS, especially those associated with scientific practices. The focus of the foundations course is not on teaching specific topics within specific disciplines, but rather on how scientific knowledge is constructed. Students are immersed in the entire process of doing science while experiencing firsthand how aspects of NOS need to be considered when constructing scientific knowledge.

In light of the reforms in science education put forth in *The Framework for K-12 Science Education*, and subsequent concerns with the first public draft of the NGSS, we urge those involved in teacher preparation or professional development to assess their program's ability to adequately prepare pre-service and in-service teachers for implementing curriculum that involves greater emphasis on scientific practices as well as NOS. The research literature is clear in that reformed instruction at the undergraduate level positively influences the use of reformed teaching methods, including the use of problem-based learning or student-led investigations, by those students when they go out in the field (Adamson et al., 2003; Keys & Bryan, 2001; Trumbull et al., 2006). Further study will follow to determine if our instructional approach influences related teaching practices in the field.

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