Teaching the Nature of Science: Successful Strategies in an Introductory College-Level Astronomy Course *Pre-Publication Draft Aug. 2009*

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Abstract: Student ideas about the nature of science (NOS) were compared at the end of one semester in a transformed astronomy course that included an embedded curriculum to explicitly teach NOS and a traditional astronomy course in which NOS was not explicitly taught. The curriculum in the transformed course gave students practice in evaluating whether science found outside of class is genuine science or pseudoscience; it also provided students opportunities to discuss how they learn science. Giving students opportunities to practice and discuss NOS led most students from the transformed course to believe that anyone can do science, whereas many more students from the traditional course believed that only individuals with innate abilities for science can do science. Furthermore, students from the transformed course valued making sense of science more than students from the traditional course.

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1. Introduction & Previous Work

Understanding the nature of science (NOS) – how science works and the nature of scientific knowledge has been seen for decades as important to the scientific literacy of the general populace (Miller, 1989; Miller, 1998). Scientific literacy can no longer be reserved for only scientists because non-scientist members of our society are and will continue to confronted with personal and public policy decisions that involve science (e.g. from what course of medical treatment for cancer to pursue to how to vote on issues concerning Earth's environment). This demands a working knowledge of what science is, how scientific knowledge is developed, as well as the limitations of science.

Although crucially important, NOS traditionally has neither been taught nor assessed. At least two factors confound efforts to do so. First, disagreements over the specifics of NOS have and still do exist. Second, instruments for assessing students' views about the nature of science have inherent limitations. Concerning the first factor, recent strides have been made within the science education community to identify generally agreed upon aspects of NOS (see Lederman, 1992; McComas, 2004; and Abd-El-Khalick, 2008). The results of these efforts may now provide a common ground for NOS discussions. With respect to the second factor, forced-choice instruments and open-ended interviews have limitations associated with suitability for a given audience, pertinent depth and breadth of individual and collective items, and relevant context of and content of the items (EBAPS home page). Furthermore, forced-choice instruments may not enable students to adequately express their own ideas, and open-ended instruments or interviews may require follow-up questions that potentially lead students towards particular responses (Sandoval, 2003).

Despite these pragmatic limitations, an increasing number of teachers, particularly in K-12 levels and in pre-service teaching programs, are specifically targeting NOS through their course curriculum. For example, strategies that have been implemented include puzzle-solving activities (Clough, 1997), pictorial gestalt switches (Michaels and Bell, 2003), activities that require students to make inferences from limited data sets, and an emphasis on the importance of scientific language (e.g. terminology such as law, theory, prove, true) (Clough and Olson, 2004). Published examples of similar efforts at the college level (excluding pre-service teaching programs) to teach NOS are scarce.

Various efforts have been made to assess students' views about NOS before and/or after having taken traditional science courses. "Traditional" is used here to indicate that NOS is <u>not</u>

explicitly taught as a part of the science course curriculum. A recent study focused on atmospheric science majors at a large research university (Parker et al., 2008). Seventeen juniors and seniors participated in a study where they completed the Views of Nature of Science Questionnaire version C (VNOS-C) during the first week of classes; 3 of these 17 students also consented to be interviewed. Based on their findings, Parker et al. recommended explicit integration of teaching NOS in atmospheric science undergraduate courses. Another study, by Adams et al. (2006), used the Colorado Learning Attitudes about Science Survey (C-LASS) to measure individual changes in student attitudes after having taken a traditional physics course as compared to their attitudes at the start of the course. over 7000 students from 60 different college-level physics courses participated in the study. The C-LASS instrument was used to measure how "expert-like" and "novice-like" students' views about learning science were. Adams et al. found that in every application of the survey to introductory physics classes, the overall class populations became less expert-like in their views about learning science. Their findings support Sandoval's (2003) idea that *doing science doesn't necessarily change ideas about science*.

With respect to the field of astronomy, surveys of those who teach introductory college-level astronomy courses indicate that an important learning goal of these teachers is to increase students' understanding of the nature and process of science (Slater et al., 2001). Most astronomy courses, however, do not explicitly address NOS through assigned home-work or other activities designed to give students practice thinking about the nature or process of science. Even astronomy lab activities that are supposed to provide scaled-down examples of doing science rarely ask students to think about and discuss the meaning of what they are doing. Such curricula apparently assume that just by learning astronomy content or doing science activities students will automatically obtain more expert-like ideas about NOS. The findings of Adams et al. (2006), however, suggest that students' do <u>not</u> develop more expert-like views about NOS when NOS is either only implicitly taught or not taught at all; in fact they are likely to develop more novice-like views.

The study herein described discusses the efforts of one college-level astronomy instructor to explicitly teach NOS to primarily non-science majors enrolled in an introductory level astronomy course <u>and</u> to assess their ideas about NOS. This study is part of a larger project to investigate what it means for introductory level astronomy students to understand NOS and apply scientific thinking in their own lives. Four overarching questions govern this larger project:

(1) What are students' conceptions of what science is?
(2) In what ways do students think scientifically?
(3) Can students distinguish genuine scientific results from bogus ones?
(4) What level of scientific literacy can students obtain?

Addressing the comprehensive findings of the larger project is beyond the scope of this article and will be presented in a future article.

The objective of this study was to examine the following question: *What is the status of introductory level astronomy students' views about the nature of science knowledge and learning science after receiving a semester of traditional astronomy instruction or transformed astronomy instruction?* This project involved two different introductory astronomy courses for non-science majors, which were taught by two different instructors. Both courses taught a similar astronomy curriculum (e.g. discuss current knowledge about the Sun, stars, and origin of life/universe); however, they varied dramatically with respect to teaching NOS. One course was taught in a traditional manner, in which NOS was only implicitly covered during the course of instruction. The other course was a transformed course in which Duncan (the first author) explicitly taught about NOS using an embedded NOS curriculum within the base astronomy curriculum. Another distinction between the two course is that the traditional course was the first of a 2-course sequence that meets a core science requirement whereas the transformed course was the second in a similar 2-course sequence. Hereafter, students is the course that received traditional instruction will be referred to as the "Control Class" and the students in the transformed course will be referred to as the "Test Class." Both classes enroll primarily freshmen and sophomores and have about equal numbers of males and females.

2. Embedded NOS Curriculum

In order to explicitly teach NOS to his students, Duncan developed a NOS curriculum that was embedded within the primary astronomy curriculum of his course. The NOS curriculum was driven by four overarching learning goals and executed through activities that stimulated student thought about science (genuine science and pseudoscience) and learning science. The activities were implemented under the premise that giving students practice at thinking, reading, writing, and talking about science and their experiences learning science would allow them to develop more expert-like understandings of NOS.

2.1. NOS-Related Learning Goals

The NOS-related learning goals of the transformed course included the following. Students will be able to:

(1) Discuss NOS and specifically discuss the question of "What is science?"
(2) Develop metacognitive skills for learning science.
(3) Distinguish between genuine science (whether executed well or poorly) and bogus science (i.e. pseudoscience).
(4) Recognize how the terms *theory*, *model*, and *believe* differ between scientific and lay contexts.

2.2. NOS-Related Activities

To facilitate an understanding of NOS among the students – in particular, to develop their views about the nature of science knowledge and views about learning science – the primary interventions used were weekly pre-planned explicit in-lecture discussions and periodic take-home assignments. These discussions amounted to ~10% of the total in-lecture time during the semester. The discussions fell into two general categories, *cases of contemporary pseudo/science issues* and *personal views on learning science*. Given that the class attendance averaged 150 on any given lecture day, these in-lecture discussions were technology-supported. First, PowerPoint slides were projected on a large screen that was used to display visual images (e.g. photos of products), graphical data (e.g. results of car safety tests or mid-term exam results), and pose multiple-choice questions. Then iClicker software and hardware were used by both the instructor and students in order to collect student responses to the questions during a polling session. After the polling session, the instructor was able to display the results of the poll and engage students in a whole-class discussion.

2.2.1. Cases of Contemporary Pseudo/science Issues

Approximately 25% of the cases discussed were drawn from astronomy and 75% from other sciences. All involved scenarios that students might encounter in their own lives. Personal relevance was a more important criterion for the selection of cases to discuss than was whether the case dealt with astronomy. Part of the teaching strategy was to promote the value of the application of NOS in students' own lives. Richard Feynman was once asked to define science and, in response, he said, "Science is a way of trying not to fool yourself." Duncan uses this statement with the addition of "or be fooled by others" in his transformed course as an effective hook for engaging students in learning about NOS because no one likes to be fooled. Although not assessed, using cases of personal relevance in NOS discussions were likely particularly useful to the non-science majors taking the course because non-science majors commonly believe that science does not apply to their day-to-day lives [Stempien, unpublished]. Below are examples of the actual cases and discussion questions involving *contemporary pseudo/science issues*:

Example A: (1) Pose the question and have the students vote on: Which vehicle is safer to drive? Simultaneously show photos of each one of the vehicle choices (Toyota Camry, Jeep Cherokee, and Ford F-series pick-up). (2) View i-Clicker histogram of polling results. (3) Display and discuss data concerning deaths associated with each vehicle type.

Example B: (1) Pose the question and have the students vote on: If you are African-American in the US today, which job are you more likely to have? (a) Sports (playing or coaching) and/or (b) Science and engineering (including medicine). (2) Ask students to choose from among the following answer choices: (A.) (a) is more likely, (B.) (b) is more likely, (C.) About the same, and (D.) (b) is ten times more likely than (a).

Example C: (1) Pose the question and have the students vote on: How many people do you think have psychic power or extra-sensory perception? (A) Only a few people, (B) All people do but some have it more than others, and (C) No one has been able to demonstrate such powers in a repeatable way when carefully tested. (2) Tell a Sherlock Holmes story about being observant. (3) Pose the same question and have the students vote again.

2.2.2. Cases of Personal Views on Learning Science

Non-science majors often hold views about learning science that can hinder their ability to learn science (Arthurs and Stempien, unpublished). Developing a working knowledge of NOS – what science is, how scientific knowledge is developed, as well as what the limitations of science are – goes hand in hand with the ability to learn science. A part of the embedded NOS curriculum in the transformed astronomy course therefore directly addressed students' views about learning science. An attempt to simultaneously reveal and shape students' views about learning science was also done through explicit technology-supported in-lecture discussions based on specific scenarios. These discussions often led to a return to two metacognitive questions, (a) How do you learn science? and (b) How do you know when you know? Examples of the actual scenarios and discussion questions involving *personal views of learning science* include:

Example A: (1) Present Bloom's Taxonomy. (2) Discuss the fact that this class requires students to do more than simply memorize facts.

Example B: (1) Present mid-term grade distribution from the previous year. (2) Discuss what is needed to earn a particular grade in the upcoming mid-term. Contrast the grades of students who participate in peer discussion during class to those who just listen.

2.2.3. Take-home Assignments

In addition to the pre-planned explicit in-lecture discussions about NOS, seven take-home assignments were also designed to be a part of the embedded NOS curriculum. Generally, these assignments required students to read about a case and provide a written response to associated questions. The first student assignment is shown in Figure 1. The readings associated with each assignment often presented surprising data, such as on the safety of different vehicles (e.g. what looks big and safe often isn't) and stereotypes (e.g. what you see in the media often doesn't reflect reality). Discussion of the readings and students' responses to the associated questions emphasized the need for actual data rather than a reliance on appearances, anecdotes, or "gut feelings." One reading assignment described a test that showed how astrology works (i.e. it depends on psychology, not astronomy). Two reading assignments involved alien abductions and

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repressed memory syndrome as examples of how personal experience is not always reliable. Other reading assignments involved so-called psychics, who look impressive on YouTube but are impressively exposed in other videos. Several reading assignments involved medical or health issues and were particularly thought-provoking because students, their family members, and/or their friends had related personal experiences.

It is worth noting that some assignments were deliberately provocative because the goal was to have students recognize that scientific topics can affect their lives in serious ways. For example, when discussion vaccination-refusers (i.e. those who believe vaccines cause autism and refuse to have their children vaccinated) students are shown a photo of a polio ward from the days before polio vaccines. When asked, less than 5% of the students had ever seen such a photo. When discussing "natural medicines" students are told about the story of a professional baseball player who died from using Ephedra. The baseball player was 23 years old, similar in age to most of the students in the class. Discussion of these examples produced a strong reaction from many students, which provided a ripe opportunity for teaching about NOS in the context of day-to-day realities. All the assignments are available at http://casa.colorado.edu/~dduncan/pseudoscience

Go to the www or to YouTube, or both. Find two science websites or videos on scientific subjects, one that you think is really good, and one that you think is bogus. If you can find sites related to the science of astronomy, great, but other sciences are fine.

For the "bogus" site, I'll be most impressed if you find something that looks credible, but is actually not true.

Write the web addresses or identifying information from YouTube here:

Good site: ________________________________

Bogus site: ________________________________

Now comes the most important part of the exercise. Explain how you decide whether something you read or see on the web is true or false. How did you decide that your bogus site was not telling the truth? Do you apply the same criteria to something you see on TV or read in the paper? Please be thoughtful about your answer, and write it here. Turn this paper in to your learning assistant in recitation.

Each recitation will, as a group, make up a list of common characteristics of good, believable sources, and another one of sources that are trying to fool you. Your LA will email this to me and I will choose the best. - D^2

Figure 1. The first "science vs. pseudoscience" assignment was given out during the first week of class.

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3. Assessment

Three different techniques were used to assess the end-of-semester status of the Control and the Test classes's end-of-semester status of their views about the nature of science. The student populations of the Control Class and the Test Class were similar in terms of male and female ratios, science and non-science major ratios, and distributions of different grade levels They were administered a forced-choice instrument called "Epistemological Beliefs Assessment for Physical Science" (EBAPS), participated in structured interviews to answer open-ended questions about the nature of science, and were asked on their final exams whether their class changed the way that they think about science. Acknowledging the aforementioned limitations of these kinds of assessment techniques alone as well as the difficulty in capturing comprehensive student thoughts about NOS, our objective was to use their combined results to provide a "snapshot" of students' views after having received a semester's worth of traditional and transformed instruction about NOS within the context of an introductory college-level astronomy course.

3.1. Epistemological Beliefs Assessment for Physical Science

The EBAPS is a 30-item forced-choice instrument, which was initially developed and validated by Andrew Elby, John Frederiksen, Christina Schwartz, and Barbara White at the University of California at Berkeley. The intended audiences for EBAPS administration are high school and college level students enrolled in physics, chemistry, or physical science courses. The two introductory level astronomy courses (i.e. traditional and transformed) involved in this study integrated elements of physics and chemistry throughout the curriculum. Although the EBAPS was not expressly designed for astronomy courses, we thought it could still be a valuable instrument in our study. We were particularly interested in seeing whether any differences emerged between the Control Class and the Test Class in terms of their responses to the subclasses that comprise the EBAPS. These subclasses include: (1) structure of scientific knowledge, (2) nature of knowing and learning, (3) real-life applicability, (4) evolving knowledge, (5) source of ability to learn, and (6) overall NOS. The EBAPS is available at http://www2.physics.umd.edu/~elby/EBAPS/home.htm.

The EBAPS was administered at the end of the semester to students in the Control Class and the Test Class. The Control Class had a complete response rate of 172 students, and the Test Class had a complete response rate of 69 students. The difference in response rates may be due to differences in the incentives provided in each course for completing the survey.

Out of the 30 EBAPS questions, only 6 questions solicited student responses that were statistically different between the Test Class and Control Class (See Figure 2). In terms of the EBAPS subclasses, 4 questions came from the *subclass 5: source of ability to learn* (Q 9, 16, 22, and, 25), 1 question came from the *subclass 6: overall NOS* (Q 4), and 1 question came from the *subclass 2: nature of knowing and learning* (Q 30). We interpret the collective responses to the first 5 aforementioned questions as an indication of students' ideas about **who can do science** and the responses to the last question (Q 30) as an indication of the importance that students place on **making sense of science**. Figure 3 shows a typical example of one of the 6 questions where the responses significantly differed between the Control Class and the Test Class.

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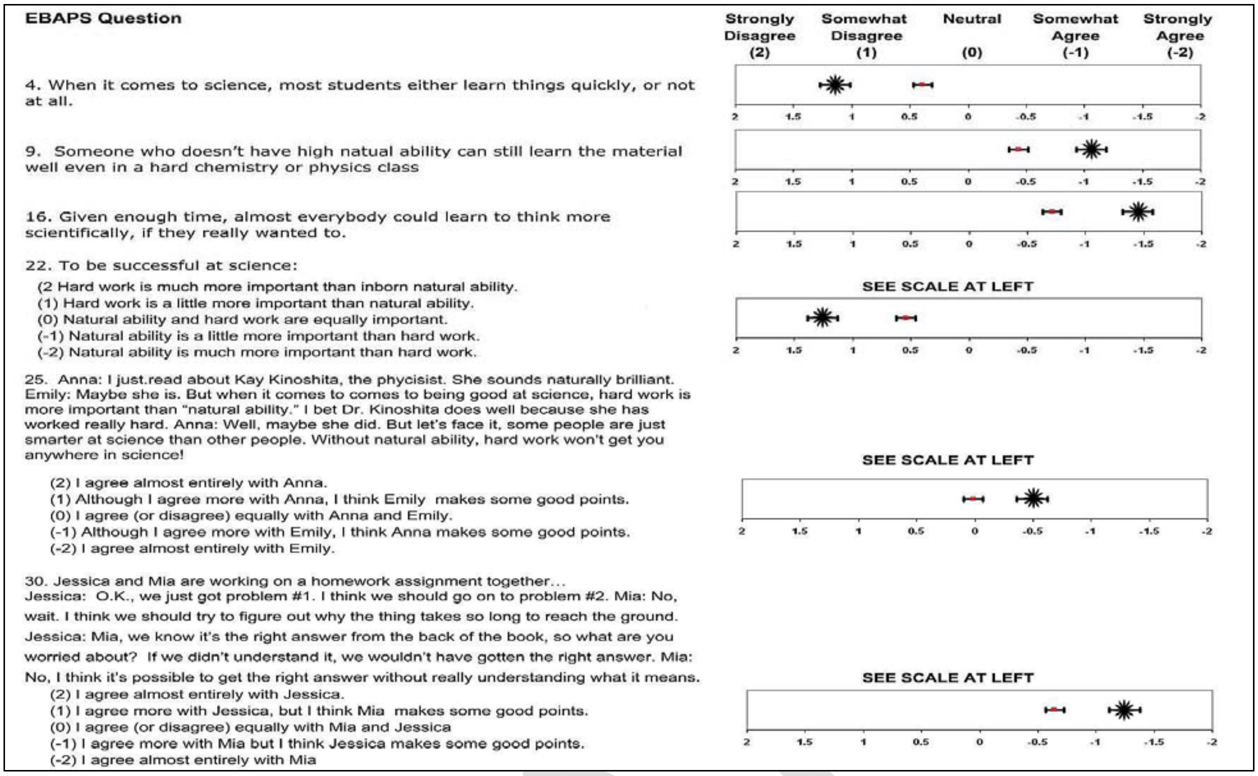

Figure 2. Six EBAPS questions solicited differences in student responses from the Control Class and the Test Class that were statistically significant. Test class: stars; control class: squares.

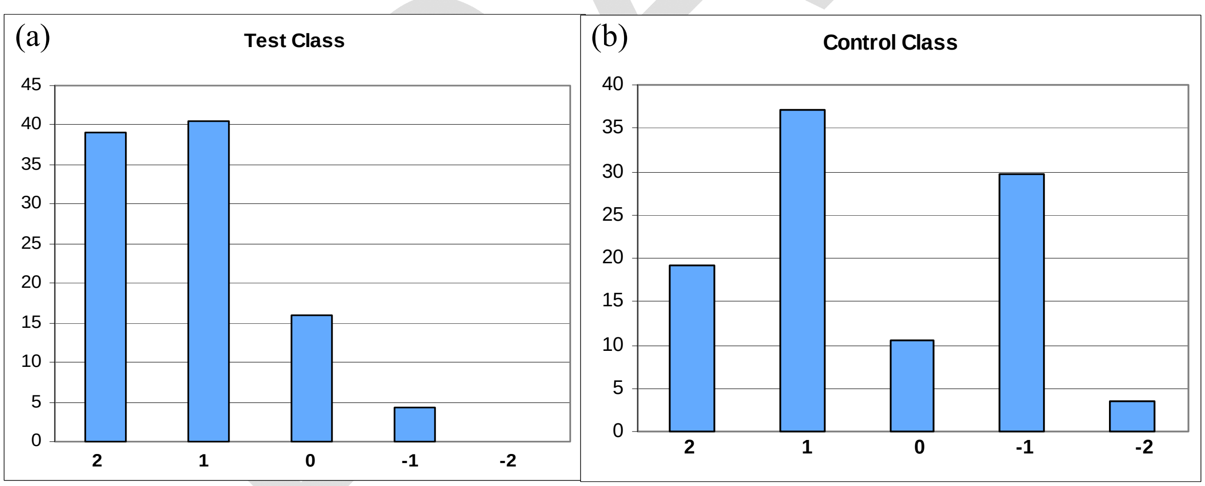

Figure 3. (a) Test Class and (b) Control Class responses to the EBAPS question, "When it comes to science, students either learn quickly, or not at all." On the x-axis, 2 represents "strongly disagree," 1 represents "disagree," 0 is neutral, -1 "agree," and -2 "strongly agree."

The responses differ substantially, as may be quantified through a chi-square test of the null hypothesis that the two samples could have been drawn from the same population. Table 1 shows the data for both classes, as well as the expected data if both samples are summed together and the responses of the 5 bins taken as the average of the two samples. Chi-squared is equal to the sum of the squared differences between observed and expected, divided by the expected (since the variance in a counting experiment such as this follows a Poisson distribution; $\sigma^2 = n_{expected}$)

Observed values

Test class	27	28	11	3	0
Control class	33	64	18	51	6

Expected values

Test class	17	26	8	15	2
Control class	43	66	21	39	4

Table 1. Note that the two classes had different numbers of student respondents.

The reduced Chi-sq for 9 degrees of freedom is 22.2, showing negligible chance that the differences are not real. A Kolmogorov-Smirnov test of the two cumulative distributions produces a difference statistic $D = 0.30$. The corresponding probability is $p < 0.001$ that the difference between the two classes is due to chance.

We also compared the classes by forming a single average index for each question in each class: average response = $2 * N_{\text{strongly disagree}} + N_{\text{disagree}} - N_{\text{agree}} - 2 * N_{\text{strongly agree}}$. Figure 2 plots this index for the 6 questions where the classes differ significantly. For the question discussed above the difference exceeds 4σ. For all 6 questions it exceeds 3σ.

3.2. Student Interviews

For the purposes of the overall project the interviews were comprised of 9 questions. Five of the 9 questions were developed by Duncan, and 4 were drawn from the "Views of Nature of Science" (VNOS) Questionnaire version C (VNOS-C). The VNOS-C was authored by Fouad Abd-El-Khalick (University of Illinois at Urbana-Champaign), Randy Bell (University of Virginia), and Norm Lederman and Renee Schwartz (Oregon State University). The authors suggest that the VNOS-C be administered as a written questionnaire and that the administration be followed up with individual interviews to insure the validity of the instrument. For the purposes of our project, however, we did not ask students for written responses to the selected VNOS-C questions and instead asked the questions during student interviews. The 9 interview questions asked are included below. Questions #1, 6, 7, and 8 were derived from the VNOS-C.

1. What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?
2. What is a scientific theory?
3. What is the scientific method?
4. Does following the scientific method guarantee you will achieve correct results?
5. Does following the scientific method improve your chances of getting correct results?
6. After scientists have developed a theory (e.g. atomic theory), does the theory ever change? If you believe that theories do change, explain why we bother to teach scientific theories. Defend your answer with examples.
7. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypothesis formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these different conclusions possible if scientists in both groups have access to and use the same set of data to derive their conclusions?
8. Some claim that science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that science is universal. That is, science transcends national

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and cultural boundaries and is not affected by social, political, and philosophical values, and intellectual norms of the culture in which it is practiced.

If you believe that science reflects social and cultural values, explain why. Defend your answer with examples. If you believe that science is universal, explain why. Defend your answer with examples.

9. Richard Feynman is has been quoted as saying, "Science is a way of trying not to fool yourself. What do you think he meant?

The complete results of the interviews will be presented in detail in a future paper. Here we report on one question: "What is a *scientific* theory?" (The word scientific was emphasized.) Twenty students from the Control Class and 23 students from the Test Class were interviewed. In addition, 9 students who had not yet taken an astronomy course were interviewed. To examine and compare their responses, Duncan developed a 2-category rubric prior to rating student responses for what he considered an *expert-like understanding* and a *novice-like understanding* of what a scientific theory is. Responses were categorized as novice-like if they included ideas such as "(just) an idea," "a guess," "an opinion or hypothesis" without mentioning any testing. Responses were categorized as expert-like if they included phrases such as "based on [any of the following] data, evidence, experiment, and/or observations" or "a tested idea." The rubric was intended to reflect the common confusion between a *scientific theory* and the everyday use of the word *theory*. Using the rubric to rate student responses, the authors had an initial inter-rater reliability of 89%. All discrepancies in ratings were resolved through discussion. Figure 4 summarizes the findings. They show that no statistically significant difference is observed in the percentages of students in the Control Class and Test Class that hold an expert-like understanding and a novice-like understanding of what a scientific theory is. Students in both classes have more expert-like understandings of what a scientific theory is compared to students that had not yet studied astronomy. Given that understanding *what a scientific theory is* is a demonstrated area of deficiency with respect to students' ideas about NOS (Abd-El-Khalick et al., 2008) and that this is demonstrated in the responses of students in this study that had not yet taken an astronomy course, the instruction students received in both the traditional and transformed courses seem to have successfully facilitated their attainment of a more expert-like understanding of what a scientific theory is.

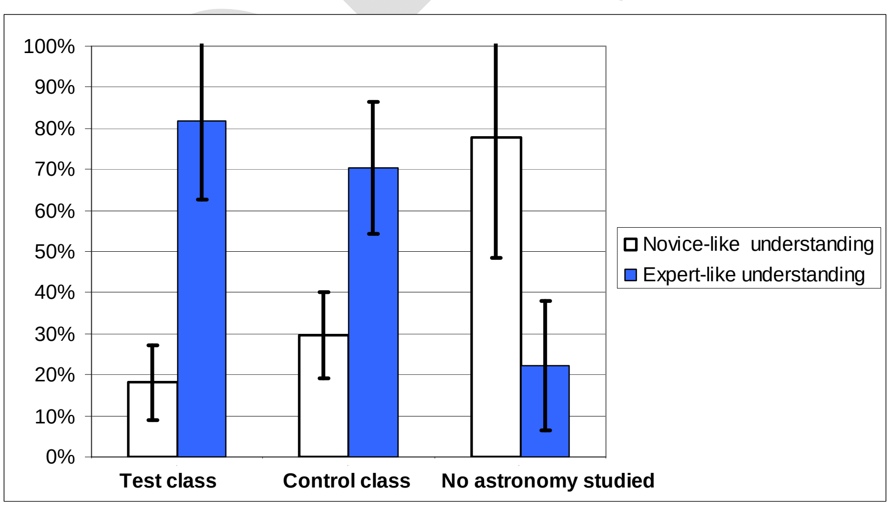

Figure 4. Students in the first week of astronomy instruction ("No astronomy studied") misunderstand the use of the word "theory" when speaking of scientific theories.

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3.3. Final Exam Question

A final assessment of students' views about science in both the Control Class and the Test Class comes from a question asked on the final. The final question of the final exam was, "Has this class changed the way you think about science? If so, how?" A small amount of credit was given for *any* answer. From each class, 116 student responses were randomly selected, reviewed, and coded. During the initial coding process, 19 different categories emerged. The 19-category rubric was used by 2 independent coders to then code the student responses. It is worth noting that the students' open-ended responses were such that one student could give a response with a variety of comments that fell under different categories within the rubric. Inter-coder reliability was greater than 95% and all initial disagreements were resolved through discussion. For the purposes of this manuscript, here we summarize key findings in Table 2.

It is worth noting that, as with the interview and EBAPS data, the student responses to the open-ended final exam question are self-reported perceptions and we did not have a means of verifying their accuracy in the students' day-to-day lives.

Type of Response	Control	Test
I learned about pseudoscience or can distinguish pseudoscience from science.	1	49
I question the credibility of information more, can find credible sources of information, and am able to make more educated decisions (and be less fooled by scams).	7	75
I learned a lot about astronomy topics and now I notice these things more in my surroundings and environment (e.g. phases of the moon, shadows, etc.).	72	38
I might/will learn more about astronomy either on my own (e.g. google, reading books, etc.) or by taking a class.	42	18
I changed my views about the nature of science (e.g. what we know changes over time, astronomy is more than just memorizing facts, etc.).	25	23

Table 2. Number of students associated with each type of response.

The most notable differences between student responses from the Test Class versus the Control Class deal with the ability to distinguish pseudoscience from science, the ability to be more critical in their approach to receiving information, and the ability to make better informed decisions. These findings are undoubtedly a consequence of the embedded NOS curriculum used in the transformed course.

Another notable difference is visible in the higher number of students from the Control Class who explicitly mentioned learning about one or more specific astronomy topics and being more aware of them in their environment. Recalling that the student responses were free writes to an open-ended question, it is possible that although students from the Test Class also learned many astronomy topics (as evidenced by their exam scores), their new knowledge of pseudoscience and the abilities they acquired through the embedded NOS curriculum were much more at the forefront of their minds and therefore possibly overshadowed specific astronomy topics that they learned.

A third difference is in the almost double the number of students from the Control Class who claimed that they would/might continue to learn more about astronomy either independently or by enrolling in another course. In this regard one must remember that the Control Class was the first course of a 2-course sequence that satisfies the core science requirement and the Test Class was the second course in such a sequence. In fact, many students from the Test Class said that they intended to take the second course in the sequence to satisfy the core science requirement.

A final comparison in this particular data set shows that similar numbers of students shared comments that expressed how their views on the nature of science had changed. These comments related to, for example, how they now know that scientific knowledge changes with time, that physics is intimately connected to astronomy, that astronomy is more complicated than originally perceived, etc. This finding is perhaps surprising in light of the goals for the embedded NOS curriculum. However, the embedded NOS curriculum did not address these aspects of science as consistently and with as much focus as it did with goal #3 (stated under Section 2.1) and it is likely that these findings are a reflection of this difference within the curriculum itself.

4. Conclusion

The embedded NOS curriculum in the transformed astronomy course provided students regular opportunities to practice thinking, reading, writing, and talking about genuine science, pseudoscience, and how they learn science. Students from the transformed astronomy course showed significant differences in their ideas about NOS when compared to students from the traditional astronomy course. We were able to distill three major differences using the EBAPS, student interviews, and a final exam question.

The 6 EBAPS items that showed differences between the Test and Control classes were not a random subset of the 30 EBAPS items. In particular, 5 of the items related to the question of “Who can do science?” The differences in responses between the two classes were large, and all support our first important finding:

> *Overall, students in the Test Class believed that anyone can do science if they work at it, whereas many more students in the Control Class believed that one must have natural ability in order to do science.*

The sixth EBAPS item that showed a significant difference dealt with the nature of knowing and learning science, particularly the importance of making sense of science. Student responses to this item support our second finding:

> *Overall, students in the Test Class valued making sense of science as part of their learning experience more than students in the Control Class did.*

The combination of survey results and student responses to the unprompted essay question at the end of the final exam lead to our third finding:

> *The strategy of giving students practice distinguishing good and bad science in applications outside of the introductory astronomy class leads them to self-report more confidence in their ability to distinguish good science from bad, and that they are more likely to think critically in their own lives.*

As the National Science Standards suggest, “…in order to participate effectively in a democracy, citizens must understand the nature of scientific claims that increasingly influence or even become matters of public debate.” They must also be willing to participate. The present investigation shows that explicit instruction of NOS and regular practice enhances this important outcome.

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We plan to use the results of this study to develop a survey instrument designed specifically for use in introductory level astronomy courses to evaluate the effectiveness of instruction on students as well as their attitudes and beliefs about science through a Collaboration of Astronomy Teaching Scholars (CATS) research project.

Acknowledgements

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