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Teaching the Nature of Science in a Course in Sustainable Agriculture

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ABSTRACT Claims of the (non-)sustainability of a given agricultural practice generally hinge on scientific evidence and the reliability of that evidence, or at least the perception of its reliability. Advocates of sustainable agriculture may dismiss science as purely subjective, or at the other extreme, may inappropriately elevate scientific findings to the status of pure objective truth. Thus, students of sustainable agriculture and natural resource management would benefit from gaining a better understanding of expert notions of the nature of science (NOS); students should learn that science is empirical, inferential, theory-laden, tentative, and creative; there is not one specific foolproof scientific method by which scientific knowledge is uncovered; and, probably most importantly in the context of sustainability, student should learn that science influences and is influenced by its wider social/cultural context. Thus, we have designed a course in sustainable agriculture that emphasizes NOS understanding. Course design elements include a rich real-world context, an inquiry setting (i.e., involving students in small-scale gardening research projects), explicit instruction in NOS concepts, and ample reflection on the intersection of NOS concepts with ideas of sustainability and farming. Student learning of NOS concepts was assessed before and after the course using a modified version of a questionnaire called Student Understanding of Science and Scientific Inquiry (SUSSI). Here we present our preliminary findings, which suggest that significant learning gains in the understanding of NOS occur during the semester, particularly in understanding the social/cultural aspects of science.

Although inherently multidisciplinary, discussions of environmental issues inevitably hinge on scientific findings. For example, a full account of the sustainability of using synthetic pesticides in agriculture requires knowledge of all of the following: the properties of the pesticide compounds (organic chemistry); the concentrations of those compounds that are present in soil, water and biological samples, and the methods and limitations of how those measurements are made (analytical chemistry); the duration, fate, and toxicity of the compounds in soils, waters and organisms (pedology, hydrology, and toxicology); and the impact of the compounds on human health and ecosystems (environmental public health and ecology). This list is not meant to imply that the environmentally literate person is one who has been trained thoroughly in each of these disciplines; if this were the case, very few if any of us would be environmentally literate. Rather, we only want to point out that discussions of environmental issues generally have large amounts of scientific content as their backdrop. It is therefore critical that if students are to become knowledgeable and active in addressing environmental issues (i.e., if we want our students to be "environmentally literate," UNESCO, 1976), they must also gain a solid grasp of the means by which the applicable scientific knowledge-base is expanded and fairly critiqued. In short, environmentally literate students must gain correct conceptions of the nature of science (NOS; see also Berkowitz et al., 2005).

A student who understands NOS can navigate such questions as: What are the methods by which scientists gain knowledge of the world? What makes scientific knowledge valid? Is scientific knowledge more or less valid than other kinds of knowledge? What are the relationships of science to society and culture? Do scientific theories change? Answers to these questions, and differences of opinion regarding their answers, are a significant part of the unspoken backdrop to discussions of science and policy. For example in the ongoing international public debate regarding the risks and safety of genetically modified organisms, both sides argue from scientific data and scientific theories, and both view the other as biased. The popular press further confuses the issue by providing a "balanced" (binary) aspect to every story on science, with experts to back up both positions. To the outside observer, these debates seem unsettled, or incapable of ever being settled, even though the bulk of peer-reviewed publications (the scientific consensus) favor one view over the other. Altogether, the public's view of science is weakened and/or confused; it may be easier for a student who is concerned about the environment to be dismissive of science than it is to work from science toward environmental goals. Making a convincing argument for teaching NOS for environmental/ecological literacy, Berkowitz et al. (2005, p. 248) noted that many students have naïve notions about NOS, and "[t]hese notions include the ideas that every question has opposing answers with scientists behind them, that science is completely subjective (e.g., radical relativism), or that science and its intellectual tools are part of the problem we all face with the environment

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Abbreviations: NOS, nature of science; SUSSI, Student Understanding of Science and Scientific Inquiry.

and therefore cannot be part of the solution. It is incumbent upon environmental educators to repudiate these naïve notions and replace them, as much as possible, with more sophisticated and productive views of science." At the other extreme, advocates of sustainability may naively and inappropriately elevate the ability of science to "prove" the objective truth of their side of an environmental argument (Steel et al., 2004).

Even expert views of NOS are contentious and changing. For example, in keeping with ideas formed in the early years of Western science, some scientists may define science as the pure and objective pursuit of truth, in which all things in the natural world will eventually become knowable through reductive scientific investigation; this is the logical positivist position (Steel et al., 2004). However, most working scientists adhere to more modest views of NOS, admitting to some subjectivity and bias in the scientific endeavor, and acknowledging boundaries to scientific knowledge given the complexity of our subject matter (Steel et al., 2004). Yet in spite of the unsettled views, seven relatively non-controversial facets of NOS have been tested against numerous philosophers of science and practicing Ph.D. research scientists (Wong and Hodson, 2009), and have been widely adopted in the science education literature (National Research Council, 1996; Lederman, 2002; AAAS, 2011). These seven aspects of NOS might frame Berkowitz's "sophisticated and productive views" of NOS so needed for environmental literacy (Berkowitz et al., 2005). The nature of science is:

- *Empirical*: Science demands data as evidence;
- Inferential: Scientific theories are models and inferences drawn from evidence, which explain observations and predict future ones;
- *Tentative*: Although scientific knowledge is reasonably durable, it is never absolute nor authoritarian; scientific ideas are subject to change in the light of new observations, experimental findings, and theories;
- *Theory-laden*: Scientific explanations of observations mostly rely on already accepted theories;
- *Creative*: "Inventing hypotheses or theories to imagine how the world works and then figuring out how they can be put to the test of reality is as creative as writing poetry, composing music, or designing skyscrapers" (quotation from AAAS, 2011);
- *Embedded in a wider culture*: Science is a human enterprise, which impacts human society and culture and also responds to it;
- *Founded on no specific scientific method*: There is not one rigid step-wise scientific method by which all valid scientific knowledge has been gained. In practice, science moves forward on the basis of multiple methods, many of which are non-experimental in the classical sense (e.g., paleontology, synthetic chemistry, and much of ecology and natural history).

Thus, we set out to develop a course in sustainable agriculture through which students would gain useful understanding of these seven aspects of NOS.

Employing Best Practices in Teaching the Nature of Science

A large body of education research demonstrates that NOS concepts are difficult to teach, in part because misconceptions and naïve views of NOS ideas are reinforced not only by the non-scientific media, but also by science teachers and science textbooks (Abd-El-Khalick et al., 2008). Various methods of teaching NOS concepts have been attempted with varying degrees of success. One method that has been proposed and tested is actively engaging students in authentic scientific activities; through participation in active scientific research, many have assumed that students would learn NOS, even if the content was never made explicit (e.g., Moss et al., 2001; Bell et al., 2003). However, assessments of NOS understanding failed to demonstrate significant learning gains using these strategies (Moss et al., 2001; Bell et al., 2003). In contrast, when students undertook authentic research—but were also provided with explicit instruction on NOS concepts, given ample time for reflection on the meaning of NOS, and received explicit feedback on those reflection assignments—significant learning gains were achieved (Abd-El-Khalick and Lederman, 2000; Schwartz et al., 2004). As summarized by Schwartz and colleagues (2004), "just 'doing science' is insufficient for one to develop conceptions of NOS as promoted in reform documents." Rather, NOS learning seems to require explicit instruction and reflection alongside an authentic research context.

DESIGN OF THE COURSE

We designed this course to incorporate best practices in the teaching of NOS, within the context of what is important specifically for teaching sustainable agriculture (such as the interdisciplinary nature of the subject). Based on the recent science education literature, we identify four aspects to effective teaching of NOS, and elaborate below the manner in which these were incorporated into the class, along with the ways in which they support the specific goals of education in sustainable agriculture:

Real-World Context

Recent scholarship in STEM (science, technology, engineering, and mathematics) education emphasizes the importance of a real-world context for effectively engaging students in the material, and ultimately for the depth of their understanding in content and process (e.g., Wei and Woodin, 2011). Understanding the relationship between science and society is, in fact, one of the core competencies in a recent call for improving biology education (AAAS, 2011). This emphasis is congruent with studies in the psychology of learning where we know that learning best occurs when students make direct connections with other aspects of their lives (e.g., Bransford et al., 1999). In addition, real-world applications support the need to develop skills in interdisciplinary thinking that are needed in agricultural and ecological disciplines (Kartson and O'Connor, 2002; Berkowitz et al., 2005; Parr and Van Horn, 2006; Schroeder et al., 2006).

We designed our course to emphasize the real-world context of NOS in two ways: through applied research projects, and through observations on field trips to agricultural sites. In addition to giving experience in authentic scientific inquiry (see below), the research projects were practical investigations testing the effectiveness of specific agricultural techniques to campus gardens. Eastern Mennonite University has multiple gardens that students helped to start and manage, and that provide vegetables for the student cafeteria. This direct linkage to student lives on campus provided a natural real-world site for testing and applying principles of sustainable agriculture;

many students were thus invested in the project, learning in a way that would not have happened had labs been disconnected from their daily experiences. Other students elected to work off campus on applied mini-research, with local restaurants or local community groups.

Field trips added a further component of real-world learning as students observed first-hand the application of sustainable (and unsustainable) techniques in working agricultural settings. The high value of these "real farm" experiences to students is consistent with what is noted by other agricultural curriculum studies (e.g., Parr and Van Horn, 2006; Grossman et al., 2010). These trips gave concrete examples of how scientific thinking is applied in daily life in an agricultural setting. For instance, in touring and discussing the workings of a local organic market garden, students were able to observe crop experiments such as tests for which plants worked best as companions for pest control. Although not explicitly labeled as science by the farm manager, we discussed how this represented the application of scientific thinking (see below under "Explicit Instruction in NOS Concepts" for the importance of making these concepts explicit to students), and how it includes components of NOS.

Inquiry Setting

Recent educational theory, including as applied specifically to agricultural education (Pretty, 1995), emphasizes learning as a process rather than students as "empty vessels" to be filled with knowledge. Incorporating authentic inquiry exercises into the curriculum is recognized as an important component of learning in the agricultural sciences, including learning in science process skills (Myers and Dyer, 2006). We incorporated authentic research projects into the lab component of this course by having students design and implement collaborative projects that focused on assessing the efficacy of various sustainable agricultural techniques and designs.

Projects were implemented over the course of the semester and staged into the following activities. First, students investigated and did literature research on a subject of interest, culminating with a scientific oral research proposal to the class. At approximately the same time, students performed a series short lab exercises that trained them in a set of techniques that are recognized as key to agricultural science (Schroeder et al*.,* 2006), and that were used in the independent projects. Thus, students learned the basics of soil extraction and testing (e.g., pH, organic matter content, texture, and nutrient analysis) and crop testing (e.g., chlorophyll content, chlorophyll fluorescence photosynthesis, leaf area index, plant growth measures, and crop yield; as in Cessna et al., 2010). As was noted by Grady and colleagues (2010), providing a common set of tools for experimentation can remove the technical focus during the implementation stage itself, thus providing more intellectual space for students to focus on concepts and interpretation. In addition, these early stages of the project provided for the formative assessment that is recognized as critical to the learning process (Black and Wiliam, 1998). Experiments were implemented independently by groups and included frequent consultation with instructors. Because it was the fall semester (late August through early December, Zone 6), plant projects were limited to cool-season crops. Students were provided with several research ideas, but given ample flexibility to design their own projects. Here are three example student projects, by title:

- Exploring Nitrogen Fixation Differences in Alfalfa, Hairy Vetch, Winter Pea, and Clover
- Comparing Season Extension Techniques: Increasing Fall Availability and Variety
- A Comparison of Radish Yields under No-Till and Double Dig Tillage Systems

At the end of the project, students practiced skills in the communication of scientific results through a written research paper. Finally, we assessed student NOS ideas with a tested rubric that included explicit NOS items (Kishbaugh et al., 2012).

Explicit Instruction in Nature of Science Concepts

As noted already, implicit methods of conveying NOS—"doing science" without explicitly explaining NOS principles—appears to be an ineffective method of achieving NOS learning gains in students (Schwartz et al., 2004; Grady et al., 2010). For instance, in the absence of explicit considerations, students may focus on the mechanics of the process (e.g., techniques) rather than consider what constitutes authentic scientific inquiry (Grady et al., 2010). Our course, therefore, included explicit explanations of NOS concepts, largely in the context of the lecture section of the course. For instance, early in the course we spent 1 week giving a brief history of agriculture, (emphasizing the major agricultural revolutions: Neolithic revolution, English Agricultural Revolution of the 1800s, Green revolution), and placed this in the context of the current state of global agricultural practices. Elaborating on the historical changes that have occurred in agriculture and the cultural differences in agriculture across time and location helped students appreciate the importance of both the social/cultural context of agricultural science, and the ongoing discoveries that continuously update our agricultural practices (science's tentative nature).

Reflection

The importance of intentional reflection has been noted as a critical component of NOS learning by a number of authors (Abd-El-Khalick and Lederman, 2000; Bell et al., 2003; Schwartz et al., 2004). In our class, assignments that incorporated intentional reflection were included to encourage the internalization and processing of the explicit considerations of NOS principles. We found that intentional reflection worked best when done in multiple formats, including oral reflections (during lecture periods), written assignments (essays), and online discussions. The different formats met different learning styles of students, and facilitated the inclusion of all students in actively constructing a communal understanding of the role of science in sustainable agriculture. In our course, examples of how specific subjects connected with principles of NOS include the current debate concerning whether organic agriculture will be able to "feed the world" now and in the foreseeable future (a recent and changing field of study that illustrates the tentative nature of science, as new studies are being published) and the importance of social organization structures such as farmer field schools (we had guest speakers talking about their experiences with such organizations in different cultures, illustrating the social nature of science). Students often came to these complex issues with preconceived notions (e.g., whether GMOs are "dangerous" or not), and reflective assignments helped to challenge these ideas, setting up the type of cognitive dissonance that authors recognize as facilitating the learning process (e.g., Schwartz et al., 2004).

Students had three specific assignments during the course of the semester that incorporated constructive reflection on NOS. First, all students wrote an essay explaining how they viewed NOS applying to sustainable agriculture. This essay assignment connected closely to discussions in class; for instance, we framed our discussion of the green revolution in terms of how science may, or may not, contribute substantially to agricultural solutions (in comparison to, for instance, how economics contributes to agricultural solutions). Second, each student orally presented on a scientific study that was related to sustainable agriculture. In most cases this was a study from the primary literature that illustrated the application of science to agriculture, and thus served as a springboard for explicitly discussing NOS principles. Some examples of articles selected by students for these presentations included those by Szumigalski and Van Acker (2005), Cox et al. (2006), and Capper et al. (2008).

A third assignment that incorporated student reflection and application of NOS to agricultural sustainability was an essay on the topic of genetically modified organisms in agriculture. For this assignment, students needed to first select one specific variety of genetically modified organism in use in agriculture (e.g., *Bt* corn, "Round-up ready' soybean, 'golden' rice, or rBST). Students then needed to search the primary research literature and find eight peer-reviewed research articles (not reviews or opinion pieces), four of which pointed to negative impacts on either human health or on environmental indicators of that specific modification, and four others that indicated no impact, or positive impacts on human or environmental health. Students needed to give a one or two sentence summary of each paper, based on their reading of each title and abstract, and then give their opinion of the environmental sustainability of using of that GMO. Student responses were collected and posted anonymously on the class webpage, and students were further instructed to read over the responses of their classmates (selecting a different GMO this time), including all of the collected research article references and summaries, and then reflect and discuss, in an online forum, on the sustainability of that GMO (see also, Anderson, 2008).

Additional Course Content and Learning Objectives

There were several other aspects of this semester long, 5 hour per week class. In addition to NOS, we hoped that our students would also gain a better understanding of basic principles of plant, soil, and animal science from an agroecological perspective; learn more of the history of agriculture and sustainability; and apply these concepts to authentic research projects and to issues of science, sustainability, and society. The following major parts of the class focused on learning content other than NOS, but may have served to reinforce NOS learning by providing a broader context and conceptual framework:

- "What is sustainable agriculture?" (2 weeks): Teaching materials included readings from several major diverse figures in the sustainability movement, including the Bruntland commission of WCED (1987), and various other perspectives on the concept of sustainability as it relates to farming.
- Agroecology content (8 weeks): Foundational principles in soil, crop, and farm animal science from an agroecological perspective, primarily based on reading from the text by Gliessman (2007).
- International agriculture development (2 weeks): Perspectives on the future of agriculture in a global context. Guest speakers talked about their experiences working with agriculture in cross-cultural contexts.

METHODS

Setting and Participants

Eastern Mennonite University is small private liberal arts college, with a total undergraduate enrolment of 1075. Sustainable agriculture is an every-other-year course that provides credit toward majors in biology and environmental sustainability. The course was first piloted in 2009, and then run again with the same two instructors (two authors of this article) in the fall of 2011. In 2009 we did not collect any learning data, outside of student assignments, but did receive positive feedback from the students, implying that they believed they learned a significant amount about the nature of science. We therefore set out to collect some preliminary data on our next run of the course, in the fall semester of 2011, when 15 students were enrolled including 8 biology majors, 6 environmental sustainability majors, and 1 graduate student studying conflict transformation. All of the students had previously taken at least two college-level science courses.

Student Understandings of the Nature of Science

Students were given a modified version of the Student Understanding of Science and Scientific Inquiry (SUSSI) questionnaire (Liang et al., 2009; Shim et al., 2010) on the first and last days of class during the fall semester of 2011. Liang's SUSSI questionnaire is composed of six sections, which test student opinions of six NOS concepts; each section is composed of four 5-point Likert scale items and an open-ended writing prompt. We discarded one of the six sections (Laws and Theories), which is arguably irrelevant to agricultural science and has low reliability (Cronbach's α <0.3; Miller et al., 2010; Shim et al, 2010). Also, we used only the Likert portions of the SUSSI. The five sections of the questionnaire that were used in this study are:

1. *Observations and Inferences*: Scientific knowledge is based on empirical observations and inferences that are creatively formed from those observations; multiple perspectives and varying theoretical commitments can lead to multiple valid interpretations of the same events.
2. *The Change of Theories*: Scientific theories are subject to change, in the light of new evidence and new interpretations.
3. *Social and Cultural Influences on Science*: Science is a human enterprise, so, society and culture influence the scientific endeavor; science also has an impact on society and culture.
4. *Imagination and Creativity in Scientific Investigation*: Scientists use imagination and creativity throughout the process of scientific knowledge generation.

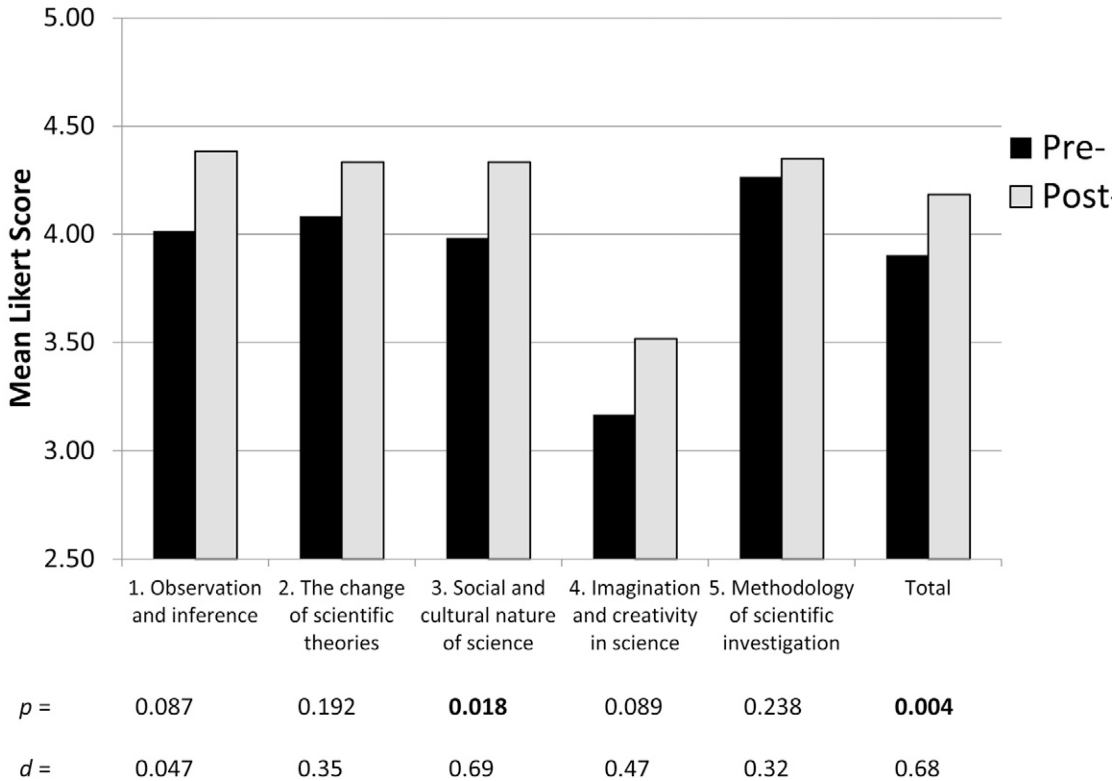

Fig. 1. Pre- and post-course mean Likert scores for five scales of NOS understanding. (*p* values are reported from two-tailed paired Student's *t*-tests. d = Cohen's *d* effect sizes).

5. *Methodology of Scientific Investigation*: There is no rigid step-by-step scientific method that results in accurate scientific knowledge.

Each of the five sections contains four statements that the students rank on a Likert scale, about half of which are reverse-coded (i.e., the more expert answer would be "strongly disagree"); scores for each scale are calculated by averaging the four selected Likert numbers, after correcting for any reversals. Thus, scores range from 1 to 5, where a score of 5 indicates an expert-like understanding and a score of 1 implies naïve misconception. To compare students' pre- and post-course scores across all of the NOS concepts, a total SUSSI score was calculated as the mean score of all subscales. Scores on the SUSSI for each category and the total were assessed using SPSS (version 18.0) software with paired two-tailed Student's *t*-tests and Cohen's *d* effect size analysis (Cohen, 1988).

We also included two open-ended questions with the survey, both pre- and post-course:

a. Briefly explain the role of science in sustainability.
b. Ideally, should agricultural science be any different than any other science? If so, in what way? [We recognize that the question is imbalanced: the second phrase ("If so, in what way?") may bias some students toward giving a positive answer. However, we were more interested in their explanation of their answer than in their yes or no.]

Below, we use student answers to question b to support the findings from the Likert-scale data (in a manner analogous to Shim et al., 2010).

FINDINGS

We recognize that our student numbers are low and therefore our conclusions are limited at this time, but we measured appreciable increases in NOS understanding. Student scores on the SUSSI questionnaire are summarized in Fig. 1. Mean Likert scores indicate that students entering the course already have strong conceptions of (1) Observation and inference, (2) The change in scientific theory, (3) Social and culture NOS, and (4) Methodology of scientific investigation, but weaker conceptions of (5) Imagination and creativity in science. The starting values in each scale are equal to or higher than most reported in the literature (for example, see Liang et al., 2009; Miller et al, 2010; and Shim et al., 2010); perhaps our department's attention to NOS education in multiple courses has led to these higher scores, making it difficult to measure learning gains, given that scores are already high. Mean scores post-course were higher than those pre-course in all five categories; using paired 2-tailed Student's *T*-tests, this increase was found to be significant ($p < 0.05$) for the social and cultural NOS subscale and for the total averaged SUSSI score. Given the small sample size, it is not surprising that a number of the statistical significance tests were not significant. Thus, as a supplement to *t*-tests, Cohen's *d* values were calculated, suggesting meaningful differences from pre- to post-test. Specifically, Cohen's *d* may be interpreted as the difference between means in standard deviation units, and is a measure of practical or meaningful significance that is minimally impacted by sample size (Cohen, 1988). That is, a Cohen's *d* value of 0.69 represents more than two-thirds standard deviation unit difference between the pre- and post-test means. Applying benchmarks determined by Cohen (1988), Cohen's *d* analysis showed medium effect sizes for scales 1, 3, and 4 and the averaged total score, and small effect size increases for scales 2 and 5 (Fig. 1). Although the low number of students gives us caution in

Table 1. Example pre- and post-course responses to the open-ended survey question: "Ideally, should agricultural science be any different than any other science? If so, in what way?" These responses show an increase in understanding the social/cultural nature of (agricultural) science.

Student	Pre-course	Post-course
A	As I see it, agricultural science is concerned with developing ways to maximize productivity and quality while minimizing harm to the environment (in other words, how do we feed the world without destroying the world). Because of the long history of farming and the unique climates where farming is practiced, it is essential that the science is relevant and specific to the area it may be implemented in.	Not necessarily. It seems to me that all science should be conducted in a way that considers social, economic, cultural, and ethical factors.
B	No, it shouldn't really be any different, because it is about running tests, following the scientific method for experiments, and gathering data in order to make decisions on how to proceed in the future. The only difference is this is about growing food and plants.	It should be more focused on sustainability and changing the system rather than keeping the same farming techniques we currently use. Yes, it should be different and should involve more environmental studies, politics, social aspects, and maybe even religion. It is probably more subjective.
C	Agricultural science takes into account the history and projection of the practice of growing food. Agricultural science is unique because it factors in improving present quality and also ensuring future food security.	Absolutely. Agricultural science needs to balance its recommendations between scientific evidence and realizing what is culturally feasible.

making conclusions that are too grand, the gains that were achieved were more dramatic than what has been reported in the literature, particularly on the "social and cultural" and "imagination and creativity" subscales (compare to Miller et al, 2010; Shim et al., 2010; Golabek and Amrane-Cooper, 2011).

Preliminarily, these data indicate that students entered this junior/senior level course already having a good understanding of most of the NOS concepts, and showed further gains in their understanding of NOS were made during the course, particularly on the social and cultural nature of science subscale.

Consistent with this finding, student responses to an open-ended question also showed change in their understanding of the social/cultural nature of science (Table 1). Students were asked the following:
Ideally, should agricultural science be any different than any other science? If so, in what way?

Responses varied from "yes" to "no," but student explanations of their answers often showed more concern for social/cultural aspects of science than did their answers prior to the course (Table 1).

Student B also started with a naïve conception of "The scientific method," and apparently altered that understanding by the end of the semester.

Of the 15 students enrolled in the class, just two of them used the words "social(ly)" or "cultural(ly)" in their answer to this question prior to the course; in contrast, 8 of the 15 used one or more of those terms to answer this question in the post-course survey. These findings corroborate the SUSSI Likert-scale data, further suggesting that at the end of the course, students are more likely to view science as a socially/culturally-embedded human endeavor.

Student course evaluations demonstrated that the students generally liked the course and found it challenging; numerical scores for "overall quality of the course," and "the extent to which the students were challenged by the course" were high, though not significantly different than the mean scores for all courses in the biology department. Student comments on the open-ended portion of the electronic course evaluation indicated wide appreciation for the laboratory portion of the course and the field trips. One student mentioned specifically that their "approach to science has been shaped by this class," clearly implying that NOS learning was a significant part of their learning from the course.

CONCLUSIONS

We have developed a course in Sustainable Agriculture appears to be effective in teaching students a more expert notion of the nature of science. Specifically, students gained in their understanding of the social/cultural nature of science. This conclusion is muted by the obvious fact that our student numbers are small and we did not collect enough data (e.g., written answers to open-ended SUSSI questions or student interviews) to confirm our findings qualitatively—we hope to do so in the coming fall. Also, we cannot know at this time whether other outside influences (such as other courses the students were enrolled in over the same semester) contributed to the measured learning gains. Yet, given the contested understanding of the nature of science and its relation to sustainability in popular discourse, and the potential ramifications of NOS understanding on policy making with respect to sustainability in farming, we are excited to teach this material in a manner that is effective, and we are hopeful that others will find aspects of this approach helpful in their own course designs.

We also note several advantages to incorporating inquiry directly into the course structure. Traditional full-fledged student participation in research projects (e.g., apprenticeship-based faculty/student collaborative projects) are time- and resource-intensive, and often benefit the top students (Prince et al., 2007; Wei and Woodin, 2011). Incorporating inquiry-based projects into the course structure exposes a wider range of students to authentic science experiences. Schwartz et al. (2004) suggest, in fact, that being in an authentic context is sufficient for learning NOS (as opposed to actually participating in scientific inquiry itself); thus, significant learning gains can potentially be achieved in less resource-intensive contexts. Also, applied research projects gave students an opportunity to practice specific agricultural techniques, thus addressing the gap between what students believe are effective techniques, but with which they have little experience (Williams, 2000).

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