Journal of Environmental Studies and Sciences
https://doi.org/10.1007/s13412-020-00594-w

ENVIRONMENTAL EDUCATION

Student representations and conceptions of ecological versus social sciences in a conservation course

Amanda E. Sorensen[1] · Jeffrey Brown[2] · Ashley Alred[1] · Joseph J. Fontaine[3] · Jenny M. Dauer[1]

Abstract
There is consensus among scientists that it is important that students understand the nature of science (NOS) and are competent in using primary literature to support understanding of complicated environmental problems. Because environmental issues involve social and ecological complexities, there is a need to create educational frameworks whereby students learn how to integrate and apply knowledge from both natural and social sciences. To explore the interplay between undergraduate students' conceptions of NOS for ecology and sociology and how students apply discipline-specific knowledge to a socio-ecological issue, we administered a NOS evaluative survey and analyzed data from student modeling practices within the context of a course-based undergraduate research experience (CURE). We found that although students held similar conceptions of the NOS for both ecology and sociology disciplines, there were notable differences in how often and how accurately students applied discipline-specific knowledge when modeling a socio-ecological system. Such insight provides guidance for the development of future educational pedagogy that supports students' ability to integrate knowledge from across natural and social sciences and applies it to real-world environmental issues.

Keywords Nature of science · Higher education · Socio-ecological systems · Learning · Ecology

Introduction

The planet is facing environmental threats at an unprecedented scale and scope, threats that are by nature social problems (Auriffeille 2005; McCarthy and King 2009). To address these global environmental problems, scholars argue that we need an integrative approach to science, education, policy, and management, engaging with the natural and social sciences as well as the humanities (Bennett et al., 2017a; Costanza and Jorgensen 2002, p.1). Because of the complexity of environmental problems and the diversity of knowledge and information required to generate potential solutions, there is a call from scholars to increase integration across disciplines in undergraduate and graduate education (Brunson and Baker 2016; Hawthorne and Wei 2016; Klemow et al., 2019) to prepare students to effectively address these problems. Indeed, there are numerous efforts toward conceptualizing educational frameworks and pedagogical approaches for ecological or environmental students that prioritize integration of social and natural sciences (see Brunson and Baker 2016; Klemow et al., 2019; Prevost et al., 2019). The emphasis in the frameworks, among others, on integration of the social and natural sciences also highlights the imperative to teach students to be able to think across the disciplinary boundaries so that they can effectively solve problems around and make decisions about environmental issues.

To create effective and robust solutions to environmental problems, scholars have noted that individuals will need to engage with scientific information across the disciplines (social and ecological) (Bennett et al., 2017a; Bennett et al., 2017b; Mascia et al., 2003; Sandbrook et al., 2013). Indeed, a persistent lack of awareness and understanding of the social sciences among conservation scientists and practitioners has been surmised to interfere with their ability to engage with knowledge generated by the social sciences productively

✉ Amanda E. Sorensen
amandaesorensen@gmail.com

[1] School of Natural Resources, University of Nebraska–Lincoln, Lincoln, NE 68583-0984, USA

[2] School of Environmental and Biological Sciences, Rutgers University, New Brunswick, NJ 08901-3502, USA

[3] Nebraska Cooperative Fish & Wildlife Research Unit, University of Nebraska–Lincoln, Lincoln, NE 68583-0984, USA

Published online: 13 February 2020

when addressing conservation problems (Bennett et al., 2017b). The disciplines can be traditionally classified as "hard" and "soft" fields of inquiry (Biglan, 1973), with "hard" fields including the natural sciences, medicine, and technology, whereas the "soft" fields include the social sciences and humanities (see Smeby 1996 for summary). At a broad level, the natural sciences and the social sciences share many of the same kinds of problems and complexities, where problems are difficult to conceptualize, variables can be difficult to measure, and there are not always clear relationships (Heberlein, 1988). However, there are differences between the social and natural sciences and, certainly within social sciences, on the foundational assumptions of ontology (i.e., what constitutes reality) and epistemology (i.e., what constitutes as knowledge or can be known) (Evely et al., 2008; Moon and Blackman 2014; Stone-Jovicich, 2015). Given that boundaries between disciplines are fuzzy and not always clearly delineated (Becher and Trowler 2001), we can broadly define the social and natural sciences as disciplinary areas that use scientific practices to understand phenomenon related to human society and the biophysical world, respectively, though various scholars recognize overlap in these areas as there has been increasing integration of areas of study and traditions to understand complex environmental problems (e.g., conservation social sciences, human dimensions of natural resource management, environmental social sciences (see Bennett et al., 2017a; Bennett et al., 2017b for full discussion)).

For students, as future environmental problem-solvers and decision-makers, to be able to refer to and apply scientific information in problem-solving or decision-making situations in the future, they must learn about the basis of scientific knowledge and how that knowledge is constructed (Tala and Vesterinen 2015). This basis of underlying values and assumptions intrinsic to scientific knowledge and its construction is known as the nature of science (NOS) (Schwartz et al. 2004; Lederman 1992). Scholars argue that student understanding of NOS is critical, as without this understanding, students lose the context that makes scientific knowledge relevant and applicable (Lederman 1998; Schwab 1962). While there are ongoing debates (Tala and Vesterinen 2015; Loving 1997; Matthews 1994; Ryan and Aikenhead 1992), there is consensus among science educators on the generalized tenets of NOS understanding (Hanuscin et al. 2006; Sandoval 2005; Osborne et al. 2003; Lederman and Abd-El-Khalick 1998; McComas and Olson 1998; Matthews 1994; Ryan and Aikenhead 1992), which include the following: Science is creative, models are important in science, and science tries to explain phenomena (see Tala and Vesterinen 2015).

Although research on individuals' understanding of NOS are often conceived of and assessed as universal, independent of context and discipline (Lederman et al. 2002; Schwartz and Lederman 2002; Palmquist and Finley 1997), recent work suggests that individuals may hold different conceptions of NOS across disciplines. Jordan and Duncan (2009) found that students held different conceptions of NOS and scientists who work in two disciplines (ecology and genetics), in addition to broader views on the value and reliability between the two disciplines. In this work, they found that the student teachers felt that the information generated by geneticist was more certain and reliable and the methods used by geneticist as more controlled and consistent across contexts. Similarly, Bezzi (1998) found that individuals hold differing views of geosciences and physics, where respondents saw physics as more objective and rigorous, whereas the geosciences was seen as more subjective and approximate. Indeed, there has been research across a variety of other subdisciplines, regardless of participant education level (students K-16 and teachers) that shows differential understanding of NOS across disciplines (Mortimer 1995; Dagher and BouJaoude 1997; Ryder et al. 1999). These differences in NOS understandings across disciplines are likely due to, in part, the notion that epistemic beliefs are discipline-specific (Hofer 2000; Pintrich 2002; Muis et al. 2006) and may influence learning within that discipline (Muis et al. 2006).

As the methods, theoretical underpinnings, epistemic beliefs, and nature of claims, may vary significantly among the scientific disciplines, it is not surprising that individuals hold varying conceptions of NOS among disciplines. Importantly, there are few studies investigating differences in student conceptions of NOS between the natural and social sciences. To help guide educational practices that teach students to engage across natural and social sciences, it is important to understand whether students hold differing conceptions of the NOS across these disciplines and, furthermore, whether they use and apply knowledge generated from each discipline differently in context.

In this paper, we ask two main questions: (1) Do students hold differing self-reported conceptions of the NOS between the natural and social sciences, and how does this change throughout a socio-ecological systems course? (2) How do students engage with or use information generated by social and natural sciences in practice, and does use relate to the students' discipline-specific NOS conceptions? In this study, we focus specifically on ecology and sociology as the two disciplines representing the natural and social sciences whereby students' NOS views are assessed. We investigate these questions in a course-based undergraduate research experience (CURE) whose focus was the socio-ecological drivers of an endangered species' management. We chose this context because previous literature notes the importance of teaching complex environmental issues through problem-based courses that focus on socio-ecological systems (Ban et al., 2015). This CURE is a course where students grapple with a socio-ecological problem, are exposed to primary scientific literature from both disciplines, and are tasked with evaluating real-world applications and limitations to their independent research and study system as a whole. To inform the first question, we assessed the NOS conceptions of ecology and sociology of students enrolled in the course. For the second question, the authors evaluated student-generated models as a metric of discipline-specific knowledge use.

Methods

CURE context

The data were collected during the fall semester of 2017 in a class that was designed as a course-based undergraduate research experience (CURE) at a large midwestern university in the USA (class is described in full in Sorensen et al. 2018). The topic of the class was the socio-ecological drivers of swift fox (*Vulpes velox*) decline in Western Nebraska. Students engaged in authentic scientific research within this system, developed their own research questions and protocols, and collected ecological and human dimensions data. What makes CUREs, including this one, an authentic research experience is that students are asking research questions of which the answer is either currently unknown or poorly informed (Bangera and Brownell 2014). In the context of this course, students were asking and answering research questions around canid species distribution in Nebraska, particularly swift fox and those canid species that influence swift fox distribution such as coyotes, which there are currently few studies (Hurtado 2016). A canid is a member of the biological family Canidae, which includes wolves, dogs, coyotes, foxes, and other dog-like mammals. While students each asked a different question, most questions centered around a canid species relationship with other canids or landscape and geographic attributes (e.g., is there a difference in coyote distribution between corn and ranching agriculture areas?). There were 28 students enrolled in the course representing all class standings (freshman-4, sophomore-9, junior-6, senior-9). A majority of students were natural resource majors (26), though there were students from the physical (1) and social sciences (1). Gender representation was skewed slightly with 18 students identifying as female, 9 as male, and 1 gender non-binary. Prior to the course, 17 students reported taking one or more social science courses (sociology, anthropology, psychology, etc.), and all 28 students reported taking one or more natural science course (biology, ecology, environmental science, etc.).

Conceptual modeling was used to support classroom instruction, allowing students to integrate and synthesize classroom instruction and outcomes of their research to generate visual representations of their conceptions of the focal system. The software, Mental Modeler (Gray et al., 2013) was chosen because it has been used in prior research in individual and collaborative contexts (Gray et al., 2012) where integrating across disciplines is necessary (see Sorensen et al., 2016). The modeling was supported by a conceptual representation framework, PMC-2E (see Jordan et al., 2014), which was designed to help students orient their thinking around complex systems and generate explanatory models (see Sorensen et al., *in revision* for modeling practice details).

Students met as a class with the instructor over four 3-h class sessions throughout the semester, with 8 weeks in between the second and third class sessions to develop and enact their research plans. Student research and further details on field protocols are described in full in Sorensen et al., 2018 and Sorensen et al., *in revision.* During each of the four class sessions, students developed and refined their individual models as they were presented with more information about the system. During the first class session, students created their initial model, which was the basis for all subsequent model revisions, based on a lecture on the community ecology and human influences on the western prairie system and swift fox. During the second class session, students read eight peer-reviewed research papers (4 representing biophysical factors, 4 representing human-dimensions factors) that represented direct and indirect drivers of swift fox populations. One of the biophysical papers was from the field of ecology, and one of the human-dimensions papers was from the field of environmental sociology. The ecology paper focused on predator-prey dynamics between coyote and swift foxes, and the sociology paper focused on global biofuel demand and greenhouse gases. The other readings included were disease transmission from prairie dogs to swift foxes (vector biology), agricultural markets and biofuel demands (economics), swift fox life history (zoology), land-use changes due to agriculture (geography), impact of urbanization/human development on coyotes (wildlife ecology), and climate change impacts on grassland ecosystems (environmental science). Students were asked to evaluate each paper in terms of the methods used to collect the data, the form the data took, the context of the study, the results from the study, and potential limitations of the data. After students evaluated the papers independently, students were led in a discussion about aspects of the nature of science tenets, focusing primarily on the largely agreed upon NOS tenets describing earlier science is creative, models are important in science, and science tries to explain phenomena– and AAAS's 1994 Benchmarks of Science Literacy – Tenets of NOS. This included talking about what constitutes as knowledge and uncertainty in that knowledge, norms and practices to generate knowledge, and how there may be differences among the disciplines' norms and practices represented in the papers. For example, the group talked about similarities across the papers such as the authors sought to explain an observed phenomenon and conclusions from each paper that were based on methodically collected data, though the types of data (population models, mortality rates of canids, economic simulations, etc.) and the process of data collection (field work, lab studies, simulations, observational studies, etc.) were different. Students also debated the tentativeness and generalizability of those papers, emphasizing the importance of scientific consensus. Further, the group also discussed how the findings from each paper could inform their individual mental models, as well as the limitations of the findings when trying to integrate that knowledge to the specific context of the class. This semi-structured discussion did not cover all the tenets of NOS but was intended to stimulate student thinking about the specific tenets that related to the practices of scientists and the validity, reliability, and implications of using knowledge generated by these different practices in their own models. This session was co-led with the instructor by a human-dimensions wildlife ecologist. Discussions of NOS were incorporated into the instructional process because NOS concepts need to be explicitly discussed and student conceptions of NOS cannot be changed through practice alone (e.g., Jones 1997; Lederman 1992; McComas 2008). During the third class session, students analyzed the class-wide aggregated data and shared their findings. During the fourth class session, students engaged in a collaborative model building activity where they were divided into groups of 3 or 4 students and asked to build a single model representative of the phenomenon based on all the information they had gathered from the class.

To develop a holistic picture of how students use and conceptualize social and natural sciences in the context of a complex socio-ecological issue, we collected data from three sources: (1) student-generated models, (2) student discussions during a collaborative model building activity, and (3) a pre-/post-survey on views of the nature of science and views of the nature of science specifically related to the two focal disciplines (sociology and ecology). All research was approved by institutional IRB (20160316036EX) and done with participant consent.

NOS conceptions between disciplines

The survey was 58 items total, 41 of which we present here (Appendix 1). The survey was administered twice to the class, once prior to the start of the course and once within a week after course completion. In our survey, we defined ecology (ecology is the study of organisms and their relationship to other organisms and their environment) and sociology (sociology is the study of human social relationships and institutions) for the students to be consistent with discussion from the course. Only students who completed both the pre- and post-survey fully were included in the analysis ($n = 25$). From the pre-/post-survey, the authors modified a previously published assessment of discipline-specific views of the NOS (Jordan and Duncan 2009) that incorporated multiple measures of student conceptions of each discipline (i.e., types of research questions scientists in different fields ask, methods to address these questions, the reliability and credibility of knowledge claims generated by this field, and the value of the field's contribution to scientific knowledge). One measure was a Likert-based questionnaire on the various aspects of NOS within each discipline (control of variables, accuracy of methods, repeatability of data, research settings, complexity of phenomena studied, certainty, tentativeness, and the extent to which experimental methods are used in the research) and about science in general.

For our study, we presented students with 30 Likert-based questions referencing our two focal disciplines (15 on ecology and 15 on sociology), 6 demographic items, and 5 questions focused on general NOS (from Jordan et al. 2015). In the general NOS questions, students responded with proportional estimates from none (0%) to all (100%) that were broken into fixed 25% intervals that could be converted to a numerical scale. Student responses were converted into a numerical scale ranging from 1 to 5 with 1 representing "none (0%)" and 5 representing "all (100%)." Due to the lack of interaction between questions, answers for pre- and post-course surveys were compared using paired *t* tests in program R. In a separate analysis to differentiate views of the NOS between the two disciplines before and after the course, the responses to the 30 Likert-based questions were analyzed using a principle component analysis (PCA) with package Vegan and FactoMineR in program R (Husson et al. 2018; Oksanen et al., 2018). PCA was selected as it is likely that several questions are correlated, and it also allows for a more complete comparison of students' views on each discipline. In addition to investigating changes in student views of the disciplines pre-to-post, we also investigated whether gender, number of social science course taken, or number of years in college influenced students' opinions on the two scientific disciplines. Due to the small sample size, class year was condensed into two categories (two or less years of college experience or three or more years of college experience).

Differences in use

From the student-generated models, model composition in terms of representation of components and relationships between components from the natural and social sciences was used as a measure of student use of discipline-specific knowledge. To assess model composition, student models were coded and compared to a target model that was co-generated with an expert wildlife biologist. The target model represented the same phenomenon students were modeling using all the information about the system the students were exposed to throughout the class. The expert and instructor then noted on the target model which components and relationships represented knowledge generated typically from either the natural or social sciences. All four individually produced models by the students were then coded by two independent coders for the presence or absence of components and accurate representation of the relationships denoted in the expert model. Relationships were scored using a proficiency scale (score of 0 to 3): 0 = no connection between components where there should be one; 1 = partially accurate, connection between components but in the wrong direction; 2 = partially accurate, connection between components in correct direction but wrong valance (±); and 3 = fully accurate, connection and valance (±) between components is correct (see Sorensen et al., *in revision* for full description of coding scheme). Based on the expert model, connections that required knowledge of human-dimensions and/or social sciences represented a possible 15 total relationships, and natural sciences represented a possible 10 total relationships. Intercoder agreement was 97%, and any discrepancies were resolved through discussions. A paired *t* test, with Bonferroni correction, was used to investigate for differences in number of components represented from each discipline. Relationship accuracy was characterized descriptively as the average number of relationships across the four models that met each score within the proficiency scale between disciplines. Only students who completed all four models were included for analysis ($n = 20$).

From the student discussions during a collaborative model building activity, the ways in which the students discussed and used natural and social science information presented in class were used as a secondary measure of student engagement with knowledge between the disciplines. Data were collected from audio recordings of the student groups as they engaged in a collaborative model building activity in the final class session. Only student groups who consented to being recorded and completed the activity were included for this stage of the analysis (total of 4 groups, $n = 14$ students). The audio recordings were transcribed, anonymized, imported to MAXQDA, and then qualitatively coded line by line using a modified coding scheme (see Sins et al., 2005) developed to describe a collaborative modeling process of a biological phenomenon (see Sorensen et al., *in revision* for full description of coding scheme). The coding scheme was comprised of three categories to describe student modeling practices: (1) cognitive process, types of reasoning the students engage in; (2) focus, the aspects of the model students attend to; and (3) knowledge, the types of knowledge (social or natural science) students use to justify their actions. Using the knowledge code allowed us to capture instances of when students were using social or natural science knowledge and how their use of specific knowledge related to the various types of reasoning (cognitive process) students expressed and specific aspects (focus) of the model they affected. Therefore, we can see if there are any differences in how these students use different areas of knowledge in their collaborative modeling process. Two co-authors independently coded the transcripts for the cognitive process and focus codes (82% and 85% respective exact match agreement), and one co-author coded for knowledge. Only one co-author, who was also the lead instructor for the course, coded for knowledge because sub-codes in this category required recognizing when students were discussing information presented in class versus prior knowledge they were bringing to the activity. Discrepancies for cognitive process and focus were resolved through discussion. A paired *t* test was used to investigate differences in number of instances when students used the knowledge from the social versus natural science (knowledge) for each category (cognitive process and focus) during the collaborative modeling process.

Results

Student NOS conceptions between disciplines

For the five items on the generalized NOS, students showed no difference in their responses before and after the course for the first four questions (Table 1). However, students showed

Table 1 Average scores from NOS questions pre- and post-course as well as associated significances in difference of scores

Question	Pre-course response M (SD)	Post-course response M (SD)	Difference in component representation (p)
What proportion of scientists rely on experiments to generate data?	4.23 (0.7)	4.08 (0.73)	*n.s.*
What proportion of scientific investigations can be conducted by people other than professionally trained scientists?	3.23 (1.04)	3.19 (0.96)	*n.s.*
What proportion of scientific theories must be based on visible data? Either to the naked eye or by using instruments such as microscopes or telescopes?	3.92 (1.11)	3.96 (0.98)	*n.s.*
What proportion of scientists reach different conclusions based on the same data?	2.77 (0.87)	3.04 (1.09)	*n.s.*
What proportion of scientific explanations are generated with indirect evidence? (examples of indirect evidence: using similar systems, using models, using experiments conducted on something else)	3.00 (0.73)	3.47 (0.75)	0.01

Scores are numerical but represent the following percentages: 1, 0%; 2, 25%; 3, 50%; 4,75%; 5,100%

changes in how they perceived the use of indirect evidence in generating scientific explanation. Before the survey, students thought that half (3.00) of scientific explanation was generated using indirect evidence, and after the survey, students thought that most (3.47) scientific explanation is generated using indirect evidence ($p < 0.05$). Results did not differ based on gender but did based on class year. Students with two or less years of college showed no significant difference in how they answered any of the questions before and after the survey. Students with three or more years in college, however, went from thinking some (2.64) of scientific explanation is generated with indirect evidence to thinking half or most (3.40) of science is generated using indirect evidence ($p < 0.01$). This difference in responses of students with three or more years of college drove the pattern seen in the overall class response.

From the Likert-based items on ecology and sociology discipline-specific NOS views, we found that students showed no significant difference in their views between the disciplines before and after the class. There was a high level of variability in responses, and 47% of the variability was captured by PC1 and PC2 (Fig. 1). Overall views on the two scientific disciplines did not differ by gender, number of social science courses taken, or college year across both pre- and post-survey results. Although there were no significant differences observed in student responses pre-to-post, there was a general increase in the students' belief that ecology is complex and

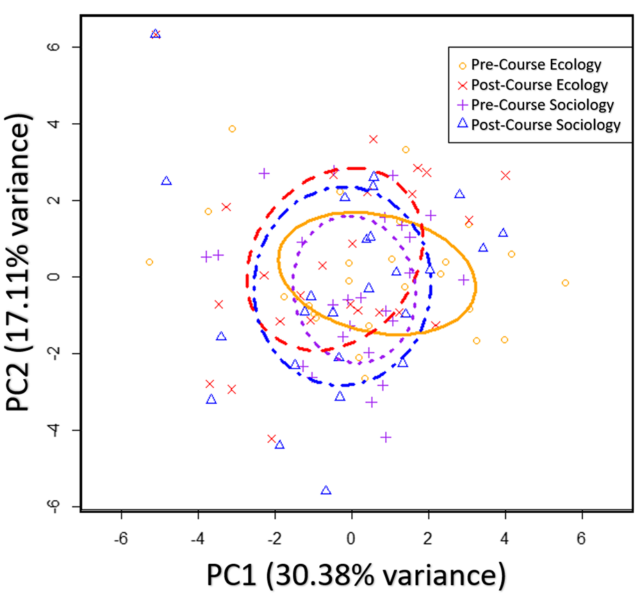

Fig. 1 Results from principle component analysis evaluating students' responses to 15 questions on the nature of science in the fields of ecology and sociology. PC1 and PC2 capture 47% of total variance in students' responses. Each shape represents all 15 responses a student gave regarding the nature of science for each field either pre- or post-course ($n = 100$, 25 students and 4 sets of answers). Ellipses represent the centroid (average) and standard deviation of the groups. No difference is seen in students' overall views of ecology and sociology both before and after the course as noted by the overlap of ellipses as well as the similar size of the ellipses (statistically confirmed with PERMANOVA)

that what is considered true in ecology may potentially change and increased disagreement that phenomena in sociology are well understood.

Differences in use

From the student-generated models, we found that there was no difference in model composition in terms of representation of components from each discipline in three of the four model iterations created by students (Table 2). In the fourth model created by students, we did see significant difference ($t(19) = -5.63$, $p < 0.005$) between the number of components from each discipline represented, with significantly more components represented from the natural sciences than the social sciences. In terms of accuracy in representation of relationships, we see a reduction of missing components and relationships entirely (0 scores) and an increase in accurate representation of components and relationships (3 scores) for both disciplines (Table 3). However, we see a greater increase in accuracy for components and relationships representing natural sciences than for social sciences. In the social sciences, students went from missing (a 0 score) on average 92% of the relationships (13.8 of the possible 15) in Model 1 to 70% (10.5 of 15) in Model 4. Conversely, students went from fully accurately (a 3 score) representing 4% relationships on average (0.6 of 15) in Model 1 to 28% (4.3 of 15) in Model 4. Partially accurate relationships (1 and 2 scores) made up less than 5% of the possible relationships on average in student models across the four models for the social sciences. In the natural sciences, students went from missing (a 0 score) on average 74% of the possible relationships (7.4 of the possible 10) represented in Model 1 to 27% (2.7 of 10) in Model 4. Conversely, students went from on average fully accurately (a 3 score) representing 11% of the possible relationships (1.1 of 10) on average in Model 1 to 62% (6.2 of 10) relationships in Model 4. Partially accurate relationships (1 and 2 scores) in the natural sciences made up 12% to 22% of the possible relationships on average in student models across the four models. From the student discussions during a collaborative model building activity, we found that there were no significant differences in representation between social science and natural science instances in either modeling process category, cognitive process ($t(5) = 0.31$, $p > 0.05$) and focus ($t(3) = 0.33$, $p > 0.05$) (Table 4).

Discussion

Here, we found that students hold similar views of NOS between the natural and social sciences, with only modest changes after engaging in the CURE, however, demonstrate more difficulty in applying knowledge from the social sciences than from the ecological sciences when generating

Table 2 Average number of components from each domain represented in individual student models created during each class meeting throughout the course

	Social science components (M (SD))	Natural science components (M (SD))	Difference in component representation (*p*)
Model 1	4.7 (2.6)	4.05 (1.6)	*n.s.*
Model 2	6.4 (2.2)	6.2 (1.8)	*n.s.*
Model 3	4.3 (1.6)	5.2 (0.9)	*n.s.*
Model 4	3.7 (0.9)	5.2 (0.5)	$p < 0.005$

A paired *t* test was run on component representation of the two domains for each model iteration (adjusted *p* value, $\alpha = 0.01$). Only students who completed all four models were included for analysis ($n = 20$)

explanatory models of the socio-ecological phenomenon. This CURE sought to explicitly engage students in the practice of science research and productively integrate knowledge from the social and ecological sciences in a socio-ecological systems context as a natural resource manager or decision-maker might do. This research suggests that as natural resource major students do not hold significantly different conceptions of NOS between disciplines evaluated here, it is possible that the observed lack of integration of the social sciences in environmental problem-solving (Bennett et al., 2017b) may not be linked to differences in NOS views between the disciplines.

Although the views of NOS for ecology or sociology did not change significantly from the beginning to the end of the course within our study, there were slight shifts within each discipline pre-to-post. For ecology NOS, students' beliefs increased throughout the course for two NOS measures: that ecology is complex and that what is considered "true" in ecology may potentially change. For sociology NOS, throughout the course, students became less convinced that phenomena in sociology are well understood. Students also reported slightly stronger belief that "truth" in sociology is more likely to change in comparison to "truth" in ecology both before and after the course. The lack of significant change we see here is similar to other work, which has found few, if any, aspects of NOS understanding change in classroom intervention time frames (Miller et al., 2010). In terms of the students' generalized NOS, we found that only one item (what proportion of scientific explanations are generated with indirect evidence?) changed pre-to-post and that class standing may influence generalized NOS understanding, but not discipline-specific NOS. It is interesting that class standing was found to be the only significant factor from our analysis in the one generalized NOS aspect (scientific explanation is generated with indirect evidence) and that this was the only item that changed pre-to-post. As those students with higher class standing (third and fourth year students) reported a more sophisticated NOS understanding, it is possible that there is some interaction effect with other interrelated factors that are likely to be correlated with higher class standing such as prior repeated exposure to primary scientific literature, research experiences, and increased comfort with foundational scientific concepts. Prior work comparing NOS conceptions between grade levels found that students at multiple grades (sixth, eighth, and tenth grade) had no differences in their NOS conceptions and all carried similar inaccurate conceptions (Kang et al., 2005). The authors of this study suggest that classroom science experiences, at least at the secondary education level, have little influence on development of NOS conceptions. While in our study students did not necessarily have an incorrect generalized understanding of NOS, prior work has found that a single

Table 3 Percent and class mean of the total relationships within each score for the four individual models across the two disciplines

		Model 1% (M)	Model 2% (M)	Model 3% (M)	Model 4% (M)
Social Sciences	0 score	92.1% (13.8)	67.3% (10.1)	72.6% (10.9)	70% (10.5)
	1 score	1.3% (0.2)	4.6% (0.7)	2% (0.3)	1.3% (0.2)
	2 score	2.6% (0.4)	4% (0.6)	1.3% (0.2)	0.6% (0.1)
	3 score	4% (0.6)	25.3% (3.8)	24.6% (3.7)	28.6% (4.3)
Natural Sciences	0 score	74% (7.4)	42% (4.2)	41% (4.1)	27% (2.7)
	1 score	8% (0.8)	14% (1.4)	13% (1.3)	11% (1.1)
	2 score	7% (0.7)	8% (0.8)	7% (0.7)	1% (0.1)
	3 score	11% (1.1)	37% (3.7)	40% (4.0)	62% (6.2)

The social sciences had a possible 15 total relationships to be scored, and natural sciences had a possible 10 total relationships to be scored (based on expert-generated target model). Scores: 0, no connection between components where there should be one; 1, connection between components but in the wrong direction; 2, connection between components in correct direction but wrong valance (±); 3, connection and valance (±) between components was correct ($n = 20$)

Table 4 Total number of instances for the sub-codes within the focus and cognitive process categories elicited from the four groups between the two disciplinary areas

Focus		Natural sciences	Social sciences
Modeling tool/action		0	0
Components		11	18
Relation		62	58
Model structure		17	10
Cognitive process			
Clarifying	*Lower Order*	2	5
Analyze		24	19
Inductive reasoning		33	35
Quantifying	*Higher Order*	5	2
Explain		11	15
Evaluate		8	4

course is not sufficient to develop a fully sophisticated NOS understanding in students (Akerson et al., 2006), and further, any effort to teach about NOS must be explicit, intentional, and specific (Smith and Scharmann 2008). However, given the change pre-to-post on the one generalized NOS item on the role of models "scientific explanation is generated with indirect evidence," this study may lend further support to the notion that NOS learning can be developed through implicit curricular approaches (i.e., engagement in scientific inquiry activities) (Abd-El-Khalick & Lederman 2000). Our CURE took a model-based approach, and after the course, students felt models and indirect evidence played a larger role in generating scientific explanations, which suggest that founding the learning and CURE process in modeling may have helped students better see the role of models and indirect evidence in explaining phenomena.

In terms of student use of knowledge from the natural and social sciences during the collaborative modeling activity, there was fairly even representation of the disciplines across the two modeling process measures (cognitive process and focus). Additionally, there was no difference in the number of components representing each discipline for three of the four models students created. As the students were presented with primary scientific papers during the course from the natural and social sciences, and the majority of students (17) reported taking at least one course in the social sciences, it might stand to reason that students would use information equally throughout the four models. However, as the majority (26 of 28) of the students participating in the class were natural sciences majors, it is perhaps unsurprising that there was greater use of knowledge from the natural sciences. Despite many of the students reporting taking at least one class in the social sciences, it is unclear if students were exposed to the underpinnings and norms of the discipline that would prepare them to grapple with primary literature and then further be able to critically think about the nature of the science within the social science papers they were presented. Some studies have shown that there are some differences between students in science and non-science majors on their views of certain NOS tenets (Chai et al., 2010; Miller et al., 2010; Liu and Tsai 2008), though no study investigating differences in NOS views on differences between social science and biological science majors to authors' knowledge. However, work comparing the views of NOS between biology and physics majors found no significant differences between the two groups (Cavallo et al., 2003), which may suggest that disparate science-oriented major classes may either intentionally or unintentionally teach students similar concepts about the nature of science.

When looking at accuracy of use of knowledge from the two disciplines is where we see divergence emerge. From the first models, on average, students accurately modeled 4% of the social sciences relationships and 11% of the natural sciences relationships that represented knowledge from the natural sciences. The limited accuracy of the initial models is not surprising, and students showed important gains in knowledge throughout the course; however, the gains in accuracy were not even for the two disciplines. In the final models, students increased the accuracy of natural science relationships by 51% over their initial models, but only 24% for social science relationships. Moreover, a greater number of the relationships that represented knowledge from the social sciences were left out of students' final models (70%) as opposed to the natural sciences (27%). Between generating the third and fourth models, students participated in the collaborative modeling activity, though it is unclear if this has a causal connection to the significant reduction in the number of components representing the social sciences in students' fourth models. Alternatively, the difference in accuracy of use between disciplines may speak to potential discomfort or disinterest in applying and integrating knowledge from the social science from students who are primarily majoring in the natural sciences. Prior work on classroom instruction of socio-ecological systems noted that students whose background was in the natural sciences can be confused by the multiple, sometimes conflicting, findings from the social sciences that result from social science researchers working in different epistemological traditions (Ban et al., 2015). While we did not see individuals holding differing discipline-specific conceptions of NOS, differences in student understanding (or lack thereof) of the methods, theoretical underpinnings, and nature of claims made between the disciplines that were not captured in the NOS survey items may have led to the difficulty students had in accurately integrating knowledge in their individual models. Further work looking into how students from the natural sciences perceive the social sciences, in terms of comfort engaging with social science information, validity of the social sciences, and applicability of knowledge generated by the social sciences to large-scale environmental problems is needed to further shed light on what may be driving the patterns we see here in this work.

Limitations

We chose one tool and curricular approach to help students learn and use knowledge across the two disciplinary areas in the context of a socio-ecological issue. It is likely that other tools and pedagogical approaches may lead to alternative outcomes in terms of changes in NOS understanding and student accuracy in their representations of the disciplinary knowledge within a system. Previous work has found success in teaching students about socio-ecological systems and to integrate across disciplines through problem-based (Ban et al., 2015; Krasny and Roth 2010) and experiential learning (Krasny 2009) strategies. Additionally, in this study, we used the consensus tenets of NOS to allow for comparison to prior studies, but our finding of students appear to apply knowledge differently based on the scientific discipline may speak to deeper differences in NOS understanding across disciplines that we were unable to measure here. There is debate among science educators around the methodology of and instrumentation around measuring NOS (Aikenhead et al., 1989; Lederman and O'Malley, 1990; Hofer and Pintrich 1997; Lederman, 1998, Abd-El-Khalick and Lederman, 2000; Lederman, 2013) and the influence of demographic and cultural factors on student conceptions and learning of NOS (see Deng et al., 2011 for a full review of the literature exploring demographics, sociocultural factors, and NOS). In this study, we accounted for gender and found that gender as a factor did not play a role in our findings, which mirrors other work that has found no differences in NOS based on gender (Conley et al., 2004; Liu and Tsai 2008). However, there are certainly other sociocultural and context-specific factors that influence and shape how individuals perceive and use science beyond gender and class standing that we measured here. While we did not seek to explore these mechanisms within this context of this research, integrating theory and findings from education psychology, science and technology studies (STS), and other disciplines will be important in informing more qualitative and holistic explorations of how individuals NOS conceptions develop for different disciplinary areas, particularly in the context of CUREs and other authentic research experiences.

Prior research also emphasizes the importance of learning context when considering changes in and development of students' NOS understanding. Scholars have suggested the importance of teaching and exploring NOS understanding in contemporary scientific contexts to provide further relevancy to students' everyday lives (Laherto 2010; Tala 2011). Although students elected to participate in this course, the specific phenomenon the course explored (swift fox conservation) may not have been personally relevant to all students. Scholars argue that students must have a more sophisticated understanding of the NOS (the basis of scientific knowledge and how that knowledge is constructed) to be able to refer to and apply scientific information in problem-solving or decision-making (Tala and Vesterinen 2015). This work sheds light on how natural resource students currently conceptualize natural and social science NOS and integrate knowledge generated across these disciplines in the context of a real socio-ecological research.

Conclusions

In the pedagogical approach we employed, students engaged in an authentic research experience around a socio-ecological problem, including field data collection efforts, conceptual modeling, and engagement with primary scientific literature. However, we found that students were not consistently able to integrate the necessary information from the social sciences to fully understand the system. The challenges we observed in our class of primarily natural resource majors may be indicative of the challenges natural resource managers and professionals experience that leads to the lack of integration of the social science in conservation practices (Bennett et al., 2017b). Further, given the lack of differences of student NOS conceptions between the social and natural sciences we observed, it is possible that the barrier to integration at the professional level is not due to a difference in NOS conceptions of the disciplines.

From this work, giving students the opportunity to engage in authentic research experiences that require engagement with disciplinary research practices from both the social and natural sciences could certainly impact the metrics measured here. As CUREs seek to give students deeper insight into science through research experiences, a similar authentic research experience that focuses on the human-dimensions element of a system that requires social science research methods and practices may be an opportunity to promote deeper engagement with and appreciation for the social sciences. In this CURE, it is possible that students in this study may have been better able to integrate the social science-related knowledge in their models if there were equal opportunity to ask and answer research questions requiring using the disciplinary practices of social science fields. Indeed, there have been numerous studies that discuss the effects of direct participation in scientific research to improve student understanding of disciplinary practices, knowledge, and research process ability (see Seymour et al., 2004 for extensive review of the literature on effects of undergraduate research experiences). Therefore, further work in exploring the impact on students' ability to engage productively with cross-disciplinary knowledge through participation in a multidisciplinary CURE experience and how to best support this type of immersive research learning experiences is needed. To prepare students to effectively address the current and future global environmental problems, educators need to help students learn, integrate, and apply knowledge from across the natural and social sciences and understanding how students currently do this can help instructors develop better pedagogical tools and teaching strategies to facilitate students' engagement with cross-disciplinary knowledge.

References

Abd-El-Khalick F, Lederman NG (2000) Improving science teachers' conceptions of nature of science: a critical review of the literature. Int J Sci Educ 22(7):665–701

Aikenhead GS, Ryan AG, Desautels J (1989) Monitoring student views on STS topics. In Annual meeting of the National Association for Research in Science Teaching, San Francisco, CA.

Akerson VL, Morrison JA, McDuffie AR (2006) One course is not enough: preservice elementary teachers' retention of improved views of nature of science. J Res Sci Teach 43(2):194–213

Auriffeille DM (2005) Environmental sociology: from analysis to action. Rowman & Littlefield

Ban NC, Boyd E, Cox M, Meek CL, Schoon M, Villamayor-Tomas S (2015) Linking classroom learning and research to advance ideas about social-ecological resilience. Ecol Soc 20(3)

Bangera G, Brownell SE (2014) Course-based undergraduate research experiences can make scientific research more inclusive. CBE Life Sci Educ 13(4):602–606

Becher T, Trowler P (2001) Academic Tribes and Territories: Intellectual enquiry and the culture of disciplines, 2nd edn. Buckingham: Open University Press

Bennett NJ, Roth R, Klain SC, Chan KM, Clark DA, Cullman G et al (2017a) Mainstreaming the social sciences in conservation. Conserv Biol 31(1):56–66

Bennett NJ, Roth R, Klain SC, Chan K, Christie P, Clark DA et al (2017b) Conservation social science: understanding and integrating human dimensions to improve conservation. Biol Conserv 205:93–108

Bezzi A (1998) What is this thing called geosciences? Epistemological dimensions elicited with the repertory grid and their implications for scientific literacy. Sci Educ 83:675–700

Biglan A (1973) The characteristics of subject matter in different academic areas. J Appl Psychol 57:195–203

Brunson MW, Baker MA (2016) Translational training for tomorrow's environmental scientists. J Environ Stud Sci 6(2):295–299

Cavallo AM, Rozman M, Blickenstaff J, Walker N (2003) Learning, reasoning, motivation, and epistemological beliefs: differing approaches in college science courses. J Coll Sci Teach 33(3):17–23

Chai CS, Deng F, Wong BKS, Qian Y (2010) South China education majors' epistemological beliefs and their conceptions of the nature of science. Asia Pac Educ Res 19(1):111–125

Conley AM, Pintrich PR, Vekiri I, Harrison D (2004) Changes in epistemological beliefs in elementary science students. Contemp Educ Psychol 29(2):186–204

Costanza, R., and Jorgensen S. E. (Eds.). (2002). Understanding and solving environmental problems in the 21st century: toward a new, integrated hard problem science. Elsevier

Dagher ZR, BouJaoude S (1997) Scientific views and religious beliefs of college students: the case of biological evolution. J Res Sci Teach 24:429–445

Deng F, Chen DT, Tsai CC, Chai CS (2011) Students' views of the nature of science: A critical review of research. Sci Educ 95(6):961–999

Evely AC, Fazey I, Pinard M, Lambin X (2008) The influence of philosophical perspectives in integrative research: a conservation case study in the Cairngorms National Park. Ecol Soc 13(2):52

Gray S, Chan A, Clark D, Jordan RC (2012) Modeling the integration of stakeholder knowledge in social-ecological system decision-making: benefits and limitations to knowledge diversity. Ecol Model 229:88–96

Gray S, Gray S, Cox L, Henly-Shepard S (2013) Mental modeler: a fuzzy-logic cognitive mapping modeling tool for adaptive environmental management. In: Proceedings of the 46th international conference on complex systems, pp 963–973

Hanuscin DL, Akerson VL, Phillipson-Mower T (2006) Integrating nature of science instruction into a physical science content course for pre-service elementary teachers: NOS views of teaching assistants. Sci Educ 90(5):912–935

Hawthorne DJ, Wei CA (2016) Learning to integrate across the natural and social sciences. J Environ Stud Sci 6(2):275–277

Heberlein TA (1988) Improving interdisciplinary research: integrating the social and natural sciences. Soc Nat Resour 1(1):5–16

Hofer BK, Pintrich PR (1997) The development of epistemological theories: beliefs about knowledge and knowing and their relation to learning. Rev Educ Res 67(1):88–140

Hofer BK (2000) Dimensionality and disciplinary differences in personal epistemology. Contemp Educ Psychol 25(4):378–405

Hurtado, L. C. (2016) *Species Distribution Model for Swift Fox in Nebraska* (Masters Thesis, University of Nebraska, Lincoln, Nebraska). Retrieved from https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1157&context=ndor

Husson F, Josse J, Le S, Mazet J, Husson MF (2018) Package 'FactoMineR'. *Package FactorMineR*

Jones A (1997) Recent research in learning technological concepts and processes. Int J Technol Des Educ 7(1–2):83–96

Jordan R, Duncan RG (2009) Student teachers' images of science in ecology and genetics. J Biol Educ 43(2):62–69

Jordan RC, Sorensen AE, Hmelo-Silver C (2014) A conceptual representation to support ecological systems learning. Nat Sci Educ 43(1):141–146

Jordan RC, Sorensen AE, Clark D (2015) Urban/suburban park use: links to personal identities? Curr World Environ 10(2):355–366

Kang S, Scharmann LC, Noh T (2005) Examining students' views on the nature of science: results from Korean 6th, 8th, and 10th graders. Sci Educ 89(2):314–334

Klemow K, Berkowitz A, Cid C, Middendorf G (2019) Improving ecological education through a four-dimensional framework. Front Ecol Environ 17(2):71–71

Krasny ME (2009) A response to Scott's concerns about the relevance of environmental education research: applying social-ecological systems thinking and consilience to defining research goals. Environ Educ Res 15:189–198

Krasny ME, Roth WM (2010) Environmental education for social-ecological system resilience: a perspective from activity theory. Environ Educ Res 16:545–558

Laherto A (2010) An analysis of the educational significance of nanoscience and nanotechnology in scientific and technological literacy. Sci Educ Int 21(3):160–175

Lederman NG, O'Malley M (1990) Students' perceptions of tentativeness in science: development, use, and sources of change. Sci Educ 74(2):225–239

Lederman NG (1992) Students' and teachers' conceptions of the nature of science: a review of the research. J Res Sci Teach 29:331–359

Lederman NG (1998) The state of science education: subject matter without context. Electron J Sci Educ 3(2)

Lederman NG, Abd-El-Khalick F (1998) Avoiding de-natured science: activities that promote understandings of the nature of science. In: McComas W (ed) *The nature of science in science education: Rationales and strategies*. Kluwer, Dordrecht, pp 83–126

Lederman NG, Abd-El-Khalick F, Bell RL, Schwartz RS (2002) Views of nature of science questionnaire: toward valid and meaningful assessment of learners' conceptions of nature of science. J Res Sci Teach 39:497–522

Lederman NG (2013) Nature of science: past, present, and future. In: *Handbook of research on science education*. Routledge, pp 845–894

Liu SY, Tsai CC (2008) Differences in the scientific epistemological views of undergraduate students. Int J Sci Educ 30(8):1055–1073

Loving C (1997) From the summit of truth to its slippery slopes: science education's journey through positivist-postmodern territory. Am Educ Res J 34(3):421–452

Mascia MB, Brosius JP, Dobson TA, Forbes BC, Horowitz L, McKean MA, Turner NJ (2003) Conservation and the social sciences. Conserv Biol 17:649–650

Matthews M (1994) Science teaching: the role of history and philosophy of science. Routledge, New York

McCarthy D, King L (2009) Introduction: environmental problems require social solutions. In: King L, McCarthy D (eds) Environmental sociology: from analysis to action, 2nd edn. Rowman & Littlefield, Lanham, pp 1–22

McComas WF, Olson JK (1998) The nature of science in international science education standards documents. In: McComas WF (ed) The nature of science in science education: rationales and strategies. Kluwer Academic Publishers, Dordecht, pp 41–52

McComas WF (2008) Seeking historical examples to illustrate key aspects of the nature of science. Sci & Educ 17(2–3):249–292

Miller MCD, Montplaisir LM, Offerdahl EG, Cheng FC, Ketterling GL (2010) Comparison of views of the nature of science between natural science and nonscience majors. CBE Life Sci Educ 9(1):45–54

Moon K, Blackman D (2014) A guide to understanding social science research for natural scientists. Conserv Biol 28:1167–1177

Mortimer EF (1995) Conceptual change or conceptual profile change? Sci Educ 4:267–285

Muis KR, Bendixen LD, Haerle FC (2006) Domain-generality and domain-specificity in personal epistemology research: Philosophical and empirical reflections in the development of a theoretical framework. Educ Psychol 18(1):3–54

Oksanen, J., Blanchet, F. G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., ... and M. H. H. Stevens. vegan: Community Ecology Package. R package version 2.5–2. 2018

Osborne J, Collins S, Ratcliffe M, Millar R, Duschl R (2003) What "ideas-about-science" should be taught in school science? A delphi study of the expert community. J Res Sci Teach 40(7):692–720

Palmquist BC, Finley FN (1997) Preservice teachers' views of the nature of science during a postbaccalaureate science teaching program. J Res Sci Teach 34:595–615

Pintrich PR (2002) The role of metacognitive knowledge in learning, teaching, and assessing. Theory Pract 41(4):219–225

Prevost, L., Sorensen, A. E., Doherty, J. H., Ebert-May, D., & Pohlad, B. (2019) 4 DEE—What's Next? Designing Instruction and Assessing Student Learning. *The Bulletin of the Ecological Society of America*, e01552

Ryan AG, Aikenhead GS (1992) Students' preconceptions about the epistemology of science. Sci Educ 76:559–580

Ryder J, Leach J, Driver R (1999) Undergraduate science students' images of science. J Res Sci Teach 36:201–219

Sandbrook C, Adams WM, Büscher B, Vira B (2013) Social research and biodiversity conservation. Conserv Biol 27:1487–1490

Sandoval WF (2005) Understanding students' practical epistemologies and their influence on learning through inquiry. Sci Educ 89(4): 634–656

Schwab JJ (1962) The teaching of science as enquiry. In: Schwab JJ, Brandwein PF (eds) The teaching of science. Harvard University Press, Cambridge, pp 1–103

Schwartz RS, Lederman NG (2002) "It's the nature of the beast": the influence of knowledge and intentions on learning and teaching nature of science. J Res Sci Teach 39:205–236

Schwartz RS, Lederman NG, Crawford BA (2004) Developing views of nature of science in an authentic context: an explicit approach to bridging the gap between nature of science and scientific inquiry. Sci Educ 88(4):610–645

Seymour E, Hunter AB, Laursen SL, DeAntoni T (2004) Establishing the benefits of research experiences for undergraduates in the sciences: first findings from a three-year study. Sci Educ 88(4):493–534

Smeby JC (1996) Disciplinary differences in university teaching. Stud High Educ 21(1):69–79

Smith MU, Scharmann L (2008) A multi-year program developing an explicit reflective pedagogy for teaching pre-service teachers the nature of science by ostention. Sci & Educ 17(2–3):219–248

Sins PH, Savelsbergh ER, van Joolingen WR (2005) The Difficult Process of Scientific Modelling: An analysis of novices' reasoning during computer-based modelling. Int J Sci Educ 27(14):1695–1721

Sorensen, A.E., Alred, A., Fontaine, J. J., and J. M. Dauer. (2018) "Integrating Modeling in a Course Based Undergraduate Research Experience." (in revision)

Sorensen AE, Jordan RC, Shwom R, Ebert-May D, Isenhour C, McCright AM, Robinson JM (2016) Model-based reasoning to foster environmental and socio-scientific literacy in higher education. J Environ Sci 6(2):287–294

Stone-Jovicich S (2015) Probing the interfaces between the social sciences and social-ecological resilience: insights from integrative and hybrid perspectives in the social sciences. Ecol Soc 20(2)

Tala S (2011) Enculturation into technoscience: analysis of the views of novices and experts on modelling and learning in nanophysics. Sci Educ 20(7–8):733–760

Tala S, Vesterinen VM (2015) Nature of science contextualized: studying nature of science with scientists. Sci Educ 24(4):435–457