Teaching Anthropogenic Climate Change Through Interdisciplinary Collaboration: Helping Students Think Critically About Science and Ethics in Dialogue

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ABSTRACT

Anthropogenic climate change is a complicated issue involving scientific data and analyses as well as political, economic, and ethical issues. In order to capture this complexity, we developed an interdisciplinary student and faculty collaboration by (1) offering introductory lectures on scientific and ethical methods to two classes, (2) assigning the same technical and opinion texts about anthropogenic climate change to both classes, and (3) coordinating multidiscipline discussions with students about their common reading assignments. Student learning was documented using identical pre- and postcollaboration surveys. We hypothesized that students would be better prepared to understand and engage in public debate about anthropogenic climate change if they were first taught to distinguish clearly between scientific and ethical claims. Our results from pre- and postcollaboration surveys support our hypothesis; as students showed an increased understanding of the distinction between science and ethics, they were better able to critically analyze popular articles and to develop their own questions about anthropogenic climate change. The results also suggest that our students were more prepared to think critically about scientific inquiry than about ethical inquiry regarding anthropogenic climate change. © *2016 National Association of Geoscience Teachers*. [DOI: 10.5408/12-331.1]

Key words: climate change, interdisciplinary, religion

INTRODUCTION

Anthropogenic climate change is an issue of popular concern and public debate (e.g., IPCC, 2007; Sherwood, 2011; Leiserowitz et al., 2012a; Roser-Renouf et al., 2014). Politicians have divergent viewpoints about what causes climate change, and what should be done about it (Germain et al., 2015). The media covers climate science and climate politics frequently (Daly et al., 2015), if imperfectly (Boykoff and Boykoff, 2007). "Climategate," a widely publicized 2009 controversy surrounding leaked electronic mail communications between climate scientists, had a measurable impact on public opinion (Leiserowitz et al., 2012b). Thus, undergraduate students come to classes already interested in, somewhat informed about, and willing to learn about the issue.

This widespread attention to climate change creates opportunities for those of us who teach about the issue. It is our experience that students who enter classes interested in the scientific data about contemporary and historical climatic changes are anxious to learn about the research methods of geoscience, creating an opportunity to reach passionate students and to introduce them to relevant subdisciplines such as climatology, glaciology, and hydrology. Furthermore, the widespread attention paid to climate change demonstrates the relevance of geoscience education, helping to make the case for introductory and general courses that cover the basic tools of this discipline.

However, anthropogenic climate change is an interdisciplinary issue with social, political, economic, and moral implications (Schneider, 1977; Chen, 1981; Shackley and Wynne, 1995; Bhaskar et al., 2010; Steffen et al., 2011; Smith and Zeder, 2013). Thus, students will also likely come to classes on climate change with questions that link geoscience to social science, public policy, and personal morality. Such questions will not be considered appropriate in all classrooms—some scientists believe that any engagement with political or moral debate in research and classrooms is inappropriate (Hsu and Agoramoorthy, 2004). However, others argue that scientists can only remain objective if they defend that objectivity in political debates (Higgins et al., 2006), or that scientists who benefit from public funding have a responsibility to help the public solve concrete problems (Lubchenco, 1998). Educators who fit into this second category of "citizen scientists" will want to prepare students not only to study climate science, but also to participate in public discussions and to critically analyze the arguments and data they will encounter in the wider world (e.g., Kolst, 2001; Fitzgerald and Baird, 2011).

The core argument of our paper is that students can learn to engage the political and moral challenges of climate change as well as science through an interdisciplinary format that emphasizes the distinction between ethical and scientific claims. Studies show that interdisciplinary collaboration with geosciences is pedagogically successful in other disciplines and in different subdisciplines of geosciences. For example, Basow et al. (2009) described a successful interdisciplinary collaboration between communications students and a glaciology research group in which communications students developed outreach posters for the research group. Students at Northern Arizona University reported improved understanding in their own discipline

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after an interdisciplinary course that drew from political science and ecology (Schlosberg and Sisk, 2000).

Our central learning outcome is for students to distinguish between scientific and ethical claims about anthropogenic climate change. We work toward this outcome using a collaboration between a glacial geologist teaching introductory geosciences courses and an ethicist teaching introductory environmental ethics courses at Pacific Lutheran University (PLU) in Tacoma, Washington.

Aside from self-selecting to enroll in our courses, we assume that students participating in our classes are representative of the PLU student body. During the 2009–2010 academic year, PLU enrolled 3,305 undergraduate students, 63% of whom were female. In general, 17% of PLU students are ethnic minorities, and 76% are from Washington State. Once each in two semesters, we developed a week of common lessons in our courses, focusing on the ethics and science of anthropogenic climate change in an effort to better prepare students to participate in public discourse about the issue. Our approach is discussed in detail in the next section.

While it is widely understood that anthropogenic climate change is a scientific issue, the inclusion of an ethical component may need further explanation. Ethics is the study of human morality, of decisions about what *should* be done in the face of uncertainty, of judgments between right and wrong, good and evil. Observations and predictions of anthropogenic climate change raise ethical questions—about the duties of rich peoples and countries toward the poor, about the duties of currently living human beings to future generations, and about the duties of the human species to the nonhuman world (Garvey, 2008; Martin-Schramm, 2010). Contemporary political debate about whether anthropogenic climate change is "real" also raises ethical issues about the values informing participants in the debate and the process by which risk and reality are assessed through economic, philosophical, and theological as well as scientific categories (Gardiner, 2010). Finally, contemporary political and engineering attempts to mitigate and slow anthropogenic climate change also raise questions about the ethical priorities of individuals and society: how to balance immediate desires with long-term goals, who should take responsibility for harms caused by systems and institutions, what can be done to encourage both individual action and large-scale institutional change, and whether human beings have a right to intentionally and fundamentally change our global environment (Gardiner, 2006; Northcott, 2007). Preparing students to engage in public discourse about anthropogenic climate change includes helping them to think and talk about these issues.

A COLLABORATIVE TEACHING EXERCISE

This exercise brought a glacial geologist teaching introductory four-credit geosciences courses into collaboration with an ethicist teaching introductory four-credit environmental ethics courses; a total of 117 students participated. The central goal of the collaboration was to help students to engage critically and intelligently in public debate about responses to anthropogenic climate change. We sought for them to learn basic facts, gain an understanding of the ways the topic is debated, and be equipped to contribute to productive public conversation. The texts assigned for this exercise were publicly available scientific, political, social, and economic discussions of anthropogenic climate change: a summary for policy makers from the Intergovernmental Panel on Climate Change (IPCC) and editorial arguments that appeared in national periodicals such as *The New York Times*, *The Washington Post*, *The Nation*, and on popular blogs and Web sites (Holmes and Niskala, 2007; IPCC, 2007; Sanford, 2007; Friedman, 2008; Gore, 2008; Romm, 2008). Future implementations of this interdisciplinary approach could identify similar, more recent readings (such as IPCC, 2014; Economist, 2015; Faiola et al., 2015; Friedman, 2015; Koonin, 2015).

We hypothesized that students would be better prepared to discuss and engage the political, economic, and social issues surrounding anthropogenic climate change if they could better articulate the distinctions and interconnections between scientific and ethical perspectives on the issue. Thus, teaching was focused on introducing students to new perspectives: The students studying ethics were introduced to a scientific view of anthropogenic climate change, while the students studying geoscience were introduced to an ethical view of the same subject. Both classes were then encouraged to identify the distinctions between these approaches and the insight gained from moving between them to develop a more comprehensive view of anthropogenic climate change.

The first semester brought students from the two classes together for collaborative exercises across three class periods. In the first period, Kevin O'Brien delivered a lecture introducing an ethical methodology and applying it to anthropogenic climate change. This lecture offered a basic definition of ethics, and critical discussion of what a society or community *should* do in response to a complicated problem. The lecture then developed a method in ethics that distinguishes factual information from normative arguments (i.e., evidence that climate change is anthropogenic is different from an argument that the U.S. should pass a cap-and-trade policy) and relates ethical arguments to the social location of the audience (i.e., an argument about anthropogenic climate change directed at students in the Pacific Northwest of the U.S. will of necessity be different from an argument about anthropogenic climate change directed at islanders in the Maldives of the Indian Ocean, a population potentially more vulnerable to impacts of climate change such as rising sea level).

In the second period, Claire Todd discussed with students the scientific method and applied it to anthropogenic climate change. This class session outlined the process of scientific inquiry and emphasized the importance of verifiable and testable data to science and the limitations of scientific claims (i.e., scientists *qua* scientists do not engage questions about what a person or group *should* do in light of scientific evidence). This lecture mirrored benchmarks for scientific literacy as outlined by the American Association for the Advancement of Science (AAAS, 2009); for example, the class discussed (1) which questions could or could not be answered using the scientific method, (2) how scientific results can influence ethical choices, but not make these choices directly, (3) the role of evidence and observations in scientific inquiry, and (4) the importance of peer-review, publication, and presentation in achieving scientific consensus (AAAS, 2009). Climate change was presented in the context of Earth's history, and as a natural process on which humans are now having a significant impact (IPCC, 2007). The foundation of this presentation was a graph of ice-core data showing natural temperature and greenhouse gas cycles over hundreds of thousands of years and showing modern, dramatic increases in greenhouse gas concentrations (Solomon et al., 2007; see curricular materials, which can be found online at http://dx.doi.org/10.5408/12-331s1). By presenting climate change as a natural process, albeit one that has been heavily impacted by human activities since 1750 (IPCC, 2007), we aimed to depoliticize discussions of climate *science* and to help students to more effectively join the debate surrounding the moral implications of and appropriate responses to human-caused climate change. For example, to assert the existence of natural and anthropogenic climate change is not controversial in and of itself; however, healthy debate *should* take place about the ethical policies and responses to scientific consensus surrounding climate change.

These lectures were interactive, involving students as participants and asking them to apply the ideas they had been taught. For example, during the ethics lecture, students worked in small groups to develop a series of ethical statements that could be made in response to scientific evidence of anthropogenic climate change (see curricular materials, which can be found online at http://dx.doi.org/10.5408/12-331s1). During the scientific method class session, students applied class concepts listed in the previous paragraph to their reading from the IPCC (2007). In these sessions, students discussed (1) how the scientific method has been used to establish consensus about anthropogenic climate change (specifically that anthropogenic emissions have very likely, or greater than 90% probability, led to increased temperatures; IPCC, 2007, 60), and (2) identified questions central to ongoing climate research. For example, the IPCC (2007, 12) reports:

> *"Model experiments show that even if all radiative forcing agents were held constant at year 2000 levels, a further warming trend would occur in the next two decades at a rate of about 0.1°C per decade...."*

This numerical modeling result allows students (1) to discuss how a model experiment reflects the scientific method, (2) to use the term "radiative forcing" as a review of the greenhouse effect and of human impacts on this natural phenomenon (IPCC, 2007; for definitions and explanations see pages 2–5 and 10–12 of the report), and (3) to discuss how this numerical modeling outcome could inform an ethical decision, but does not in and of itself define human impacts as wrong or unethical. In the same document, the IPCC (2007, 12) reports:

> *"Since IPCC's first report in 1990, assessed projections have suggested global average temperature increases between about 0.15°C and 0.3°C per decade for 1990 to 2005. This can now be compared with observed values of about 0.2°C per decade, strengthening confidence in near-term projections."*

This finding provided a foundation for discussing how repeated applications of the scientific method are essential to improving scientific understanding and producing unbiased results, a learning objective supported by the Benchmarks for Scientific Literacy (AAAS, 2009). Students also worked together to propose their own applications of the scientific method to persistent research questions in climate science.

A theme in both lectures was the distinction between positive claims of fact and normative claims of morality, between the truth claims of science, which aim for objectivity and universality, and the normative claims of ethics, which are necessarily made from particular social locations and are inevitably controversial (Dessler and Parsons, 2006; see curricular materials, which can be found online at http://dx.doi.org/10.5408/12-331s1). Scientific questions about climate change can be answered by statements of fact i.e., "is" statements, such as, "Globally averaged surface temperatures are warmer." Ethical questions can be answered by statements of norms, i.e., "should" statements, such as, "The United States should reduce greenhouse gas emissions." While scientific questions can be said to have "correct" answers, ethical statements must always be understood as arguments that depend upon perspective and social location. This distinction, while simplistic, was intended to help students make basic discernments in discussions of climate change.

In the third session, students were asked to apply their understanding of scientific and ethical methodologies to editorials from national periodicals (listed in the first paragraph of this section). This class session relied almost entirely on interactive techniques: Students worked in groups to identify those claims in these editorials that were scientific and those that were ethical. Then, students discussed the ways science is used (and misused) in public debate, and they identified the diverse audiences appealed to in the different print and digital periodicals reviewed for class.

Student oral participation and written responses during the third session demonstrated the success of our three joint sessions; we found that students were able to apply and identify scientific and ethical methodologies during critical analysis of public climate change discussion (please see our Results sections for a review of student responses). However, we also found that much of the work during our first semester of collaboration was devoted to the logistics of integrating two distinct classes. Challenges included scheduling joint sessions for classes in two different time slots and finding a space available for a larger group of students. Thus, we simplified our approach during the second semester; classes were not combined, and instead the interdisciplinary work was done through guest lectures. Claire Todd visited the environmental ethics class in order to teach about anthropogenic climate change and the scientific method, and Kevin O'Brien visited the geoscience class in order to teach about climate ethics and ethical method. In both classes, students read the IPCC report (2007) to gain an understanding of current scientific findings and critiqued a series of editorials, identifying and analyzing ethical arguments and scientific claims. We discuss our assessment methodology and results in the following sections.

ASSESSMENT METHODOLOGY

During both semesters, students completed anonymous surveys designed to measure their understanding of the role of science and ethics in public discussion of anthropogenic climate change. The same survey was administered before

TABLE 1: Selected true–false questions from pre- and postcollaboration surveys.

Question No.	True or False?
1	Public policy should not incorporate ethical beliefs.
2	Public policy should not be influenced by scientific research.
3	Personal lifestyle choices should not be influenced by scientific research.
4	Scientific research is relevant to my life.
5	Ethics is relevant to my life.
6	Climate change is not real.
7	Climate change is a natural process.
8	Human beings are not influencing the Earth's climate.
9	It is important that I know something about climate change.
10	Reasonable people can disagree about the existence of climate change.
11	Reasonable people can disagree about what to do about climate change

and after interdisciplinary collaboration, and it was not changed between the two semesters of the study. The survey consisted of true–false questions (Table I); multiple-choice questions in which students identified whether a statement is ethical, scientific, or neither (Table II); and three short-answer questions (Table III). During the first semester, precollaboration surveys were administered to 24 ethics students and 23 geosciences students; postcollaboration surveys were administered to 22 ethics students and 23 geosciences students. During the second semester, precollaboration surveys were administered to 52 ethics students and 18 geosciences students; postcollaboration surveys were administered to 56 ethics students and 17 geosciences students. Discrepancies between the number of pre- and postcollaboration survey respondents are due to student absences. In order to maintain anonymity, we did not associate surveys with individuals and thus we could not track changes in individual student responses.

True–false questions were designed to determine student understanding about naturally occurring and anthropogenic climate change (questions 6–8, Table I) and to characterize their perceptions of the roles of ethics and scientific research in personal lives and public policy (questions 1–5 and 9, Table I). Two additional true–false questions (questions 10–11, Table I) sought to determine what students thought was debatable about climate change: the existence of climate change or society's response to climate change. With these questions, we hoped to measure improvement in (1) student understanding of the consensus about climate change produced by the scientific method (IPCC, 2007; e.g., page 3 of the report states "very high confidence that the global average net effect of human activities since 1750 has been one of warming"), and (2) student understanding of the wide-ranging debate about the "right" responses by individuals and communities to the reality of global climate change. These goals are supported by Benchmarks of Science Literacy (AAAS, 2009), which state that "science can sometimes be used to inform ethical decisions by identifying likely consequences of ethical actions, but science cannot be used by itself to establish that an action is moral or immoral," and "scientists often cannot bring definitive answers to matters of public debate…the answer may involve the comparison of values that lie outside of science." Similarly, in a summary of its *Synthesis Report*, the IPCC (2014) highlights the role of "ethical dimensions" (p 17) in climate change policy. By defining for students the different processes of scientific and ethical inquiry, we aimed to improve their ability to navigate the public debate about anthropogenic climate change. We measured the significance of this improvement using the Student's t-test.

TABLE 2: Multiple-choice questions from pre- and postcollaboration surveys. Students were asked to indicate if each of the following statements is an ethical statement, a scientific statement, or neither.

Question No.	Is This an Ethical Statement, Scientific Statement, or Neither an Ethical nor a Scientific Statement?
1	"Climate change is an urgent problem."
2	"Human beings are very likely influencing the Earth's climate."
3	"The United States should have a policy addressing climate change."
4	"CO_2 concentrations have increased over the last century."

TABLE 3: Short-answer questions from pre- and postcollaboration surveys. Students were asked to respond to the following prompts.

Question No.	Short-Answer Questions
1	What does a scientist do?
2	What does an ethicist do?
3	What questions do you have about climate change?

We measured this improvement with four multiple-choice questions in which students classified statements as scientific, ethical, or neither scientific nor ethical (Table II). We provided students with two scientific statements: "Human beings are very likely influencing Earth's climate," and "CO_2 concentrations have increased over the last century." By discussing the scientific method and the IPCC report, we wanted to improve student ability to recognize each of these statements as scientific; the first statement mirrors directly the language used in the IPCC report to describe the certainty of results from scientific studies (see page 22 in Solomon et al., 2007). We also provided two ethical statements: "Climate change is an urgent problem," and "The United States should have a policy addressing climate change." While these statements could be *supported by* evidence produced by the scientific method, the statements themselves are not a product of the scientific method, but rather of an ethical decision-making process.

The survey also included open-ended questions. Two of these questions were used to assess student identification of the distinctions between scholarly inquiry in science and ethics (questions 1–2, Table III). The final question, "What questions do you have about climate change?" was designed to identify change in student inquiry as a result of our collaborative approach. As mentioned earlier, we did not associate surveys with individual students in order to protect anonymity; thus, we documented changes in responses to these questions across the student population as a whole.

RESULTS

Preexisting Understanding and Misconceptions

Quantitative Findings

Precollaboration surveys demonstrate that most students began our collaborative teaching exercise with an appreciation of the importance of both science and ethics, where 112 of 117 students agreed that scientific research is relevant to their lives, and only five thought that public policy should not be influenced by scientific research. The apparent appreciation of the relevance of scientific research was slightly weaker when students were asked to relate research to personal lifestyle choices, but still only 19 (16%) indicated that these choices should not be influenced by scientific research. In total, 116 out of 117 students agreed that ethics is relevant, and only 16 indicated that public policy should not incorporate ethical beliefs.

Precollaboration responses suggest an inherent appreciation of anthropogenic climate change. Only one student agreed that climate change is not real, and only two students agreed that humans are not influencing Earth's climate. All but two students thought it was important that they know something about climate change. In fact, students may be too quick to point to anthropogenic origins of climate change; only 90 out of 117, or 77% of students, agreed that climate change is a natural process.

Despite this overwhelming precollaboration acknowledgement of the reality of climate change, when asked about disagreement over climate change, students were hesitant to judge scientific misconceptions in other people; 62% of students agreed that reasonable people could disagree about the existence of climate change. Precollaboration responses show an appreciation of the diversity of ethical climate change arguments; 109 students, or 93%, agreed that reasonable people could disagree about what to do about climate change.

When asked to differentiate between scientific and ethical statements (Table II and Fig. 1) before our collaborative teaching activities, a majority of students (94 of 117, 82%) recognized "The United States should have a policy addressing climate change" as an ethical statement, and 100% of students recognized "CO_2 concentrations have increased over the last century" as a scientific statement. Student responses demonstrated some confusion when asked to categorize the statement "Climate change is an urgent problem"; only 43 of 117 students (38%) recognized the statement as ethical. Responses show slightly less confusion regarding the statement, "Human beings are very likely influencing the Earth's climate"; 69 of 117 students (59%) recognized the statement as scientific.

Qualitative Findings

Responses to short-answer questions (Table III) about what scientists do showed that most students were familiar with the basic methods of scientific research before our collaboration. One ethics student responded to "What does a scientist do?" with "He test hypothesis [*sic*] based on research." In response to the same question, another ethics student wrote, "A scientist comes to a conclusion or hypothesis by researching and compiling data. They can also research other hypotheses and prove them right or wrong."

Students demonstrated considerably more confusion about the role of an ethicist. In response to "What does an ethicist do?" a geosciences student wrote, "Not sure... perhaps the same as a scientist but instead uses people and their ethical/beliefs to form a conclusion on why it is we do what we do???" In response to the same question, an ethics student wrote, "Study and look at facts to see if they are ethically correct." These comments were indicative of a trend throughout the answers; students sought to understand ethics as a science, confusing the analysis of facts with the analysis of moral norms.

When asked "What questions do you have about climate change?" the most common question was about the difference between natural and anthropogenic climate change. Example responses include the following from a geosciences student: "Wouldn't climate change happen even without humans?" Some students moved quickly from this question to a policy question, such as an ethics student who asked: "What are we doing to ensure climate change isn't a natural process?" This response seems to be directed at scientific research, but its tone suggests a strong normative motivation. Another ethics student asked: "Is it all part of a natural cycle? If not, what needs to be done?" This question reflects a blurring of science and ethics: The student seems to assume that the normative question "what needs to be done" depends entirely upon the factual question "is it all part of a natural cycle?" and so is not distinguishing between positive and normative statements about climate change.

Postcollaboration Changes

Quantitative Findings

Our collaborative teaching approach had some impact on student appreciation for reasonable modes of disagreement in the public discourse about climate change. Only 55 students (47%) agreed that reasonable people can disagree about the existence of climate change, down from 73, or 62%, in the precollaboration surveys ($p = 0.01$). Only five more students agreed that reasonable people can disagree about what to do about climate change, bringing the total number of students agreeing up from 109 to 114 or 97% ($p = 0.37$).

Our collaboration also helped some students differentiate between ethical and scientific statements typical of climate change discussions: 85 students (up to 74% from 59%; $p = 0.03$) were able to identify "Human beings are very likely influencing the Earth's climate" as a scientific statement. We saw similar gains but less overall understanding in student identification of "Climate change is an urgent problem" as an ethical statement (up to 51% of responses from 38% precollaboration; $p = 0.07$).

We also measured changes in student understanding of the other discipline, the discipline of the collaborating class. Geosciences students gained an appreciation for the role of ethics in public policy; the number of false responses to "Public policy should not incorporate ethical beliefs" from geosciences students increased by 19% ($p = 0.03$). We also

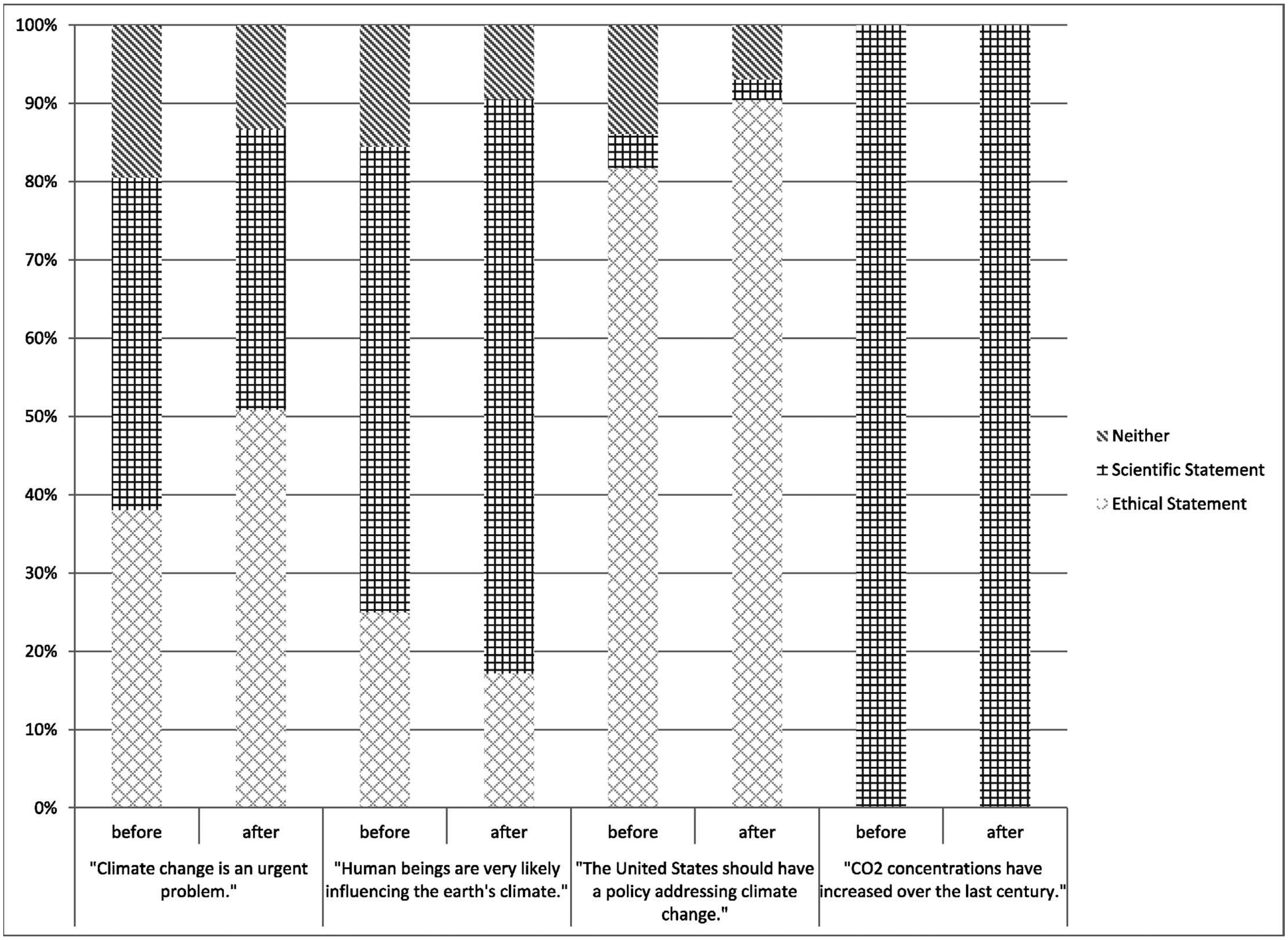

FIGURE 1: Student classification of ethical and scientific statements before and after collaborative activities.

appear to have improved ethics students' understanding of climate change, with 18% more ethics students indicating that it is false to believe that reasonable people can disagree about the existence of climate change ($p = 0.03$), and 15% more ethics students agreeing that climate change is a natural process ($p = 0.16$).

Qualitative Findings

In postcollaboration short-answer questions, students demonstrated substantial clarity about science and the scientific method. Virtually every student emphasized that science is about assessing "data" or "facts," and many emphasized the importance of experimentation and repeatable results.

In defining ethics, many students picked up on the definition provided in lecture, i.e., that ethics is about assessing what an individual or society *should* do in response to complicated problems, with one ethics student writing that ethicists "contemplate and formulate what is right and wrong." However, others continued to associate ethics with simplistic "opinions" or absolute statements about current events. Thus, in postcollaboration, there was increased clarity about ethics but still some confusion. One ethics student summed up a widespread view by answering this question with "Not entirely sure."

Answers to the third short-answer question, "What questions do you have about climate change?", revealed that while students did not entirely understand ethics, they had an improved capacity to distinguish ethical and scientific ways of thinking. For example, a geosciences student asked, "Can we change the way [climate change] is portrayed to separate the reality of the situation from the judgments on the situation?" An ethics students similarly demonstrated a sophisticated understanding of the distinction between science and ethics by asking, "Do some scientists dabble in ethical stances?" These questions and others like them suggest that a significant portion of students came to understand and could apply the distinction between science and ethics.

Another qualitative measure of our hypothesis was the in-class activity we asked students to conduct, using opinion editorial articles about climate change to demonstrate their understanding of the distinction between scientific and ethical claims in order to have a sophisticated discussion about climate change. For instance, one group carefully drew distinctions between scientific and ethical claims in a short piece by Thomas Friedman, noting that his assertion "Our kids are going to be so angry with us one day'' implies an ethical argument based on his interpretation of scientific data about climactic changes in Greenland (Friedman, 2008). The group extrapolated from this to agree with Friedman's assessment of contemporary political trends and his advocacy of education and political action in response to climate change. This is one example of the ways students demonstrated an ability to bring science and ethics into dialogue after our collaborative activities.

DISCUSSION

Our hypothesis was supported by our work: Students were better able to identify, discuss, and assess claims about climate change after they had been taught to articulate the distinctions and interconnections between scientific and ethical perspectives on the issue. In reflecting on this success, we saw the value in teaching climate change from an interdisciplinary perspective, exposing students to multiple ways of understanding and wrestling with the problems presented by this issue.

However, our surveys and qualitative assessment suggest that students are much better prepared to engage in scientific discussion of this issue as compared to ethics. We were surprised at how well informed our students were about climate change, and with how generally scientifically literate they seemed to be. This literacy may be a result of our location in the Pacific Northwest—a region characterized by substantial environmental interest, according to some surveys (Kiernan, 2015; Schwab, 2015) —and it may also reflect some self-selection in the students who enroll in courses in geoscience or environmental ethics. It also seems to demonstrate some measure of success in the previous science education of these students.

In contrast, many students were unprepared and uncomfortable thinking of and defining ethics as an academic discipline. Tendencies to avoid answering the short-answer questions about what an ethicist does and to reduce ethics to simple ''right and wrong'' statements or mere ''opinion'' suggest that students did not have a strong grasp on what ethics is and what it does, even after an introductory lecture on the topic. This may be a result of the fact that most students have likely not previously studied ethics in a formal setting, and so did not have any tools to draw on to build this understanding.

At the same time, our findings suggest that students could benefit from serious attention to ethics in general and to climate ethics in particular. The questions they offered about climate change were very much focused on policy, questions that require normative answers. For example, a geoscience student asked in the postcollaboration survey, ''What can be done? I have learned quite a bit, but the next step is, 'What Now?''' An ethics student asked a similar question: ''What can we do? How long will it take to see results? How many people does it take?'' Another ethics student made explicit a motivation behind many questions: ''Is there any hope?'' Students asking such questions are looking for help thinking about what should be done, about how people can and should respond to climate change. This suggests that courses on climate change can meet a real student need if they supplement careful teaching of science with an attention to ethics and policy.

CONCLUSIONS

Our results show that teaching students about the distinct roles of science and ethics can help them to better engage in public discussions of climate change and climate change policy. Improvements in student understanding were seen in student explanations of ethics and science, and in student ability to distinguish between scientific and ethical statements; and in-class discussion and presentations demonstrated increased capacity to think critically about climate science and climate policy. However, responses to short-answer questions reveal a persistent misunderstanding of ethical methodologies and desire for more attention to what should be done in response to climate change. Future collaborations should work to distinguish even more clearly ethical methodologies from scientific methodologies and to allow students space to develop ethical arguments of their own.

Survey responses also indicate that our students had basic scientific literacy and believed that climate change was an important issue before collaborative activities began. This suggests that the work of climate change education can move to the level of engaging the complexity of the data and the diversity of available responses to it, a teaching process well served by interdisciplinary pedagogy. By the same token, scholars who teach about climate change in the humanities should incorporate scientific analyses into their discussions.

In future collaborations, we will offer more advanced scientific information in lecture and give a more extensive introduction to ethics. This approach will help students to more fully engage in both approaches to climate change, which our research suggests will then help them better understand and participate in public debates about the issue. It is clearly worthwhile to continue interdisciplinary collaborations to fully equip students to engage climate change issues in the public sphere.

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