Linking Biophysical, Socioeconomic, and Political Effects of Climate Change on Agro-Ecosystems

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ABSTRACT

To meet the sustainability challenges of the future, we need leaders who are trained to work well in diverse, multidisciplinary teams and a populace that understands the biophysical and socioeconomic challenges facing humanity and how to meet the needs of its diverse stakeholders. With a goal of increasing climate literacy amongst college students, we developed a cooperative jigsaw activity to encourage students to explore the complexities of joint decision making when taking into account multiple perspectives. We found that undergraduate science (natural science and natural resources) students were engaged, drew on a variety of types of evidence to support claims about managing rangelands impacted by climate change, and referenced both complex social and natural systems in their postassessment. © *2014 National Association of Geoscience Teachers*. [DOI: 10.5408/13-070.1]

Key words: climate literacy, agriculture, cooperative learning, undergraduate students

INTRODUCTION

To effectively address global environmental crises and issues, citizens need to be able to make evidence-based decisions (Jordan et al., 2009; Pidgeon and Fischhoff, 2011). They also need to understand that social and natural systems are complex and that they intersect with one another. Orr (1989) argued that for students to recognize that they are a part of large ecosystems, instructors must help them explore how societal actions affect these systems. For example, human activity has resulted in increased concentrations of greenhouse gases in Earth's atmosphere that have been theoretically and statistically linked to variances in global climate systems (IPCC, 2007a; National Research Council [NRC], 2010). Despite such evidence being publicly available, many students remain unaware of the basic fundamentals of climate science, especially with regard to the effect of human activity on climate change (Kahan et al., 2012). Kahan et al. (2012) reported that the viewpoint of the social group with which one associates and its social, political, and ethical beliefs are more important determinants of one's concern about climate change risks than one's level of scientific literacy. Hence, it has been concluded that discussion and consideration of different stakeholder viewpoints may be a more effective means of increasing concern about the effects of climate change than simple information transfer (Corner, 2012).

Undergraduate science instructors have the opportunity to help increase and promote climate science literacy. In fact, college may be the first opportunity for many students to explore the multidimensionality of climate change science. Many recent high school graduates, educated under the former *National Science Education Standards* (NRC, 1996), have not formally learned about climate science during their K–12 education. In addition, undergraduate learning opportunities attract students who are either committed to or are exploring a particular field of study, bringing a diversity of perspectives to the classroom. In order to promote climate literacy, we need instructional strategies that are relevant and rigorous, engaging for both science and nonscience majors, and have accompanying assessment tools.

In this paper, we describe a cooperative jigsaw activity (modeled after Constible et al., 2007) for undergraduate students developed by our interdisciplinary team of researchers at Colorado State University. The activity was initially developed for an informal education symposium on climate change for the university community and was subsequently modified for formal undergraduate science classes. We describe the updated iteration of this activity. Our lesson was designed with three main learning objectives: to demonstrate that (1) there are multiple stakeholder perspectives that are relevant when making decisions regarding ecosystem management under a changing climate; (2) all citizens need relevant evidence to make informed decisions about mitigating and adapting to climate change; and (3) decisions and stakeholders vary across cultural and geographical contexts despite having overlapping concerns. Our curriculum addressed all seven of the climate literacy components (described below), although some were implicit, and others were explicit (U.S. Climate Change Science Program, 2009). We provided empirical evidence as examples of the types of data each stakeholder

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might find relevant to his/her perspective. To evaluate our curriculum materials, we analyzed students' pre- and postactivity written responses as they related to our learning objectives and recorded our observations regarding classroom discussions.

Climate Literacy

At a basic level, science literacy is defined in the national science education standards as having the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity (NRC, 1996; Achieve, 2013). More specifically, climate literacy requires the understanding of the interactions among humans, ecosystems, and the climate system. As outlined in a collaborative document published by the National Oceanic and Atmospheric Administration, the American Association for the Advancement of Science, and the National Science Foundation, a climate-literate individual recognizes that (1) the Sun is the primary source of energy for Earth's climate; (2) climate is regulated by complex interactions among components of the Earth system; (3) life on Earth depends on, is shaped by, and affects climate; (4) climate varies over space and time through both natural and human-influenced processes; (5) our understanding of the climate system is improved through observations, theoretical studies, and modeling; (6) human activities are affecting the climate system; and (7) climate change will have consequences for the Earth system and human welfare (U.S. Climate Change Science Program, 2009). All components were explicitly addressed in the described activity, with the exception of the first one (though it was assumed that sunlight is needed for photosynthesis, this was never explicitly discussed during the activity).

Given the complexity of climate science, the effects of human activities on climate change, and the tightly coupled nature of human and climate interactions, the content is not easily understood by the general public (IPCC, 2007; U.S. Climate Change Science Program, 2009). If we want to prepare our college students to be the next generation of scientists and engineers, college instructors must provide opportunities for them to explore complexities of atmosphere–biosphere interactions (National Academy of Science, National Academy of Engineering, and Institute of Medicine, 2007), which, unbeknownst to many science students, includes impacts on agricultural systems.

Climate Change and Agriculture

Students who are interested in learning more about climate change may not realize that agricultural lands are also affected by climate changes. Rangelands are land dominated by grasses, sedges, forbs, and shrubs and are often unfenced open lands used by grazing (grass-eating) and browsing (shrub-eating) animals. These systems make up about 50% of Earth's terrestrial surface (USDA NIFA, 2011) and are vulnerable to climate changes just like other ecosystems. While rangelands have multiple uses, grazing by wildlife and domestic livestock is a key feature of rangeland systems.

Although issues related to livestock management in both commercial and subsistence agricultural systems may appear to be different, they share similarities related to climate changes. Our interdisciplinary team included two scientists who conduct much of their research in rangelands (one in the American Western Great Plains and the other on the Tibetan Plateau). Both of these environments include extensive rangeland systems on which both wild and domestic animals forage. In recent years, American ranchers and Tibetan pastoralists have noted changes in the levels of precipitation and average temperature that have had important implications for the management of grazing animals and livelihoods. We developed two case studies centered on the Tibetan Plateau (TP) and the Western Great Plains (WGP). We chose the local WGP case study, because, as place-based climate change engagement research demonstrates, the climate change issue resonates most with people when it focuses on a place that has meaning and value to them (Schweizer et al., 2013). We chose the TP example to highlight issues of vulnerability and equity in relation to climate change.

TP Case Study

The Tibetan Plateau is the home to pastoralists who have managed herds of domestic yak and sheep for millennia. They live a subsistence lifestyle and use their livestock for food, clothing, shelter, and energy (e.g., yak dung is collected for cooking fuel and heating). Several major Asian river systems (the Yellow, Yangtze, Mekong, Salween, Brahmaputra, Ganges, and Indus Rivers) flow from the Tibetan Plateau to billions of people downstream. The Chinese government, which oversees Tibet, is interested in protecting the grasslands, as well as protecting people's access to water downstream. There is evidence, though, that climate change may be negatively affecting the grasslands and that grazing is necessary to maintain overall production, composition, and diversity under a changing climate (Klein et al., 2004, 2007).

Climate changes in Tibet include strong increases in temperature that have numerous effects on that rangeland system [Fig. 1(a)]. For example, increases in temperatures have led to altered timing of vegetative growth and delayed plant flowering (Dorji et al., 2013; Zhang et al., 2013); decreased plant diversity (Klein et al., 2004); changes in species composition, which includes the replacement of highly valued grass and grass-like species with less preferred shrubs (Klein et al., 2007); and a decrease in medicinal plant and palatable forage species (Klein et al., 2008). These changes are important because many aspects of pastoral life are dependent upon the state of the rangelands and livestock. Ecosystems and pastoralists in Tibet are vulnerable not only to increases in temperature, but also to changes in the frequency and intensity of extreme events, such as severe snowstorms, which can cause large livestock mortality (Klein et al., 2011). Precipitation extremes are predicted to increase under a warming climate, especially in regions such as Tibet, where increases in mean annual precipitation are expected (Meehl et al., 2007). There is already evidence for increases in precipitation extremes in Tibet during the spring (Fu et al., 2013), when precipitation falls as snow and when livestock are weak after surviving the winter. Livestock are vulnerable to starvation if snowstorms make vegetation inaccessible, forcing them to feed only on senesced (dead) vegetation.

Pastoralists in Tibet are accustomed to living in an extreme and dynamic environment and have developed strategies for coping with environmental change and extreme events. Some of these strategies include mobility, providing supplementary feed, and having extra labor power to respond to the snowstorms and extreme events (Klein et al., 2011; Yeh et al., 2014). However, political, social, and economic transformations in the region are constraining these coping strategies (Klein et al., 2011; Yeh et al., 2014). If herders are not able to adapt to ecosystem changes associated with climate change, their livelihood and culture could be lost.

WGP Case Study

Unlike the Tibetan case study, the Western Great Plains setting introduces a very different economic environment, as well as different biological responses to climatic change than are expected in Tibet [Fig. 1(b)]. In the WGP, rangeland resources provide forage for livestock grazing and ecosystem services. Livestock grazing is generally a commercial endeavor for which ranchers manage both the animals and rangeland to maximize their economic net returns (Manley et al., 1997). With the prospect of climate change, ranchers must be able to respond to ever-changing conditions, if they want to ensure both stability and profitability of rangelands (Brown and Thorpe, 2008). For example, ranchers must consider the impacts of livestock stocking decisions on the productivity and profitability of rangeland resources managed in this manner in light of trade-offs between stocking rates and animal performance (the quality and quantity of animal produce; e.g., meat) (Jones and Sandland, 1974). Range productivity is affected by changing environmental conditions (Ritten et al., 2010). In grazing systems, plant food (forage) availability is directly related to rainfall and climatic variability (Vetter, 2005). Ranchers have realized decreased optimal stocking rates and profits as climate conditions (including temperature and precipitation events) have become more variable than in the past (e.g., Izac et al., 1990; Manley et al., 1997).

Changes in concentration of atmospheric carbon dioxide (CO_2) also impact rangeland systems of the Great Plains; e.g., Morgan et al. (2004) demonstrated that CO_2 can enhance plant growth and lead to important shifts in the composition of the vegetation. CO_2 is a limiting resource for many plants, and as CO_2 levels increase, so does plant growth. Plants have evolved different physiological processes to photosynthesize (using carbon in the presence of sunlight to produce sugar, oxygen, and water) under different environmental conditions, which is necessary for plant growth. Hence, cool-season (C_3) and warm-season (C_4) plant populations vary in different rangeland settings. Competition among plants under increased concentrations of CO_2 is likely to be important and may favor herbaceous plants (forbs) and cool-season grasses (Morgan et al., 2007). Others have found that increases in CO_2 may favor weedy plant species, some of which are invasive (Smith et al., 2000). Higher CO_2 also reduces plant water loss, at least temporarily offsetting some of the negative effects of warmer temperatures due to desiccation, and sometimes favoring warm-season grasses when combined with warmer temperatures (Morgan et al., 2011).

While the impacts of increased CO_2 are known to affect plant and herbivore phenology (timing of biological events in response to abiotic factors, such as climate), physiology, and the hydrologic cycle, the complex interactions among plant species and the interactions with warming and grazing make absolute predictions of future consequences problematic. As CO_2 rises, ranchers may choose to manage their pastures in ways to take advantage of climate-change–induced shifts that increase desirable plant vegetation or to mitigate undesirable shifts of other plant species. Because the particular consequences of climate change on rangeland plant communities cannot be accurately predicted at this time, it is difficult to determine best practices to prepare ranchers for an uncertain future. In the face of this reality, ranchers and pastoralists will need to regularly monitor the condition of the rangeland and will find it to their advantage to maintain flexibility in their livestock operations (e.g., change species and/or class of livestock, move herds across geographic areas, modify grazing practices) in order to maintain levels of economic profitability and sustainability.

COOPERATIVE GROUP WORK

Given the complexity of climate change science, students often fail to connect the physical and biological basis of climate change with the important socioeconomic issues involved in climate change. Agricultural systems, in particular, provide good case studies in which natural and social systems can be examined, and the TP and WGP case studies were designed to illustrate how natural and social systems are interconnected. The ranchers and pastoralists must contend with scientific, socioeconomic, and political issues as they make decisions about managing their livestock. Also, their management decisions and livelihoods are affected by the broader rangeland policies to which they are subjected. We implemented and evaluated a jigsaw cooperative activity (modeled after Constible et al., 2007) in which undergraduate science students engaged in role playing of various stakeholders in either the TP or the WGP case studies.

Cooperative group work has been used as an instructional approach to help students learn how to work in groups and increase their learning outcomes (Slavin, 2003). Smith (1996) argued that the use of cooperative group work in college courses results in higher achievement in students than competitive or individual work. He identified five essential components of activities classified as cooperative: (1) positive interdependence, where all students work together to complete a task; (2) face-to-face promotive interaction, where students must engage in a problem-solving task; (3) individual accountability/personal responsibility, where each individual is assessed; (4) teamwork, where through leadership and communication, students must make decisions, manage conflicts, build trust, and develop strategies in order for work to be completed; and (5) group processing, where groups must have opportunities to evaluate the effectiveness of their group work dynamics. The role of the instructor, therefore, is to support these five elements by providing clear objectives and information regarding assessment.

A jigsaw activity is grounded in a cooperative learning model that emphasizes role taking. Within jigsaw activities, students assume the role of an expert on a specific component necessary to answer a question or solve a problem (Moore, 2009). Often jigsaw activities are broad enough that they can accommodate several experts that examine different perspectives of an issue. For example, Constible et al. (2007) developed a jigsaw cooperative activity during which students need to consider whether or

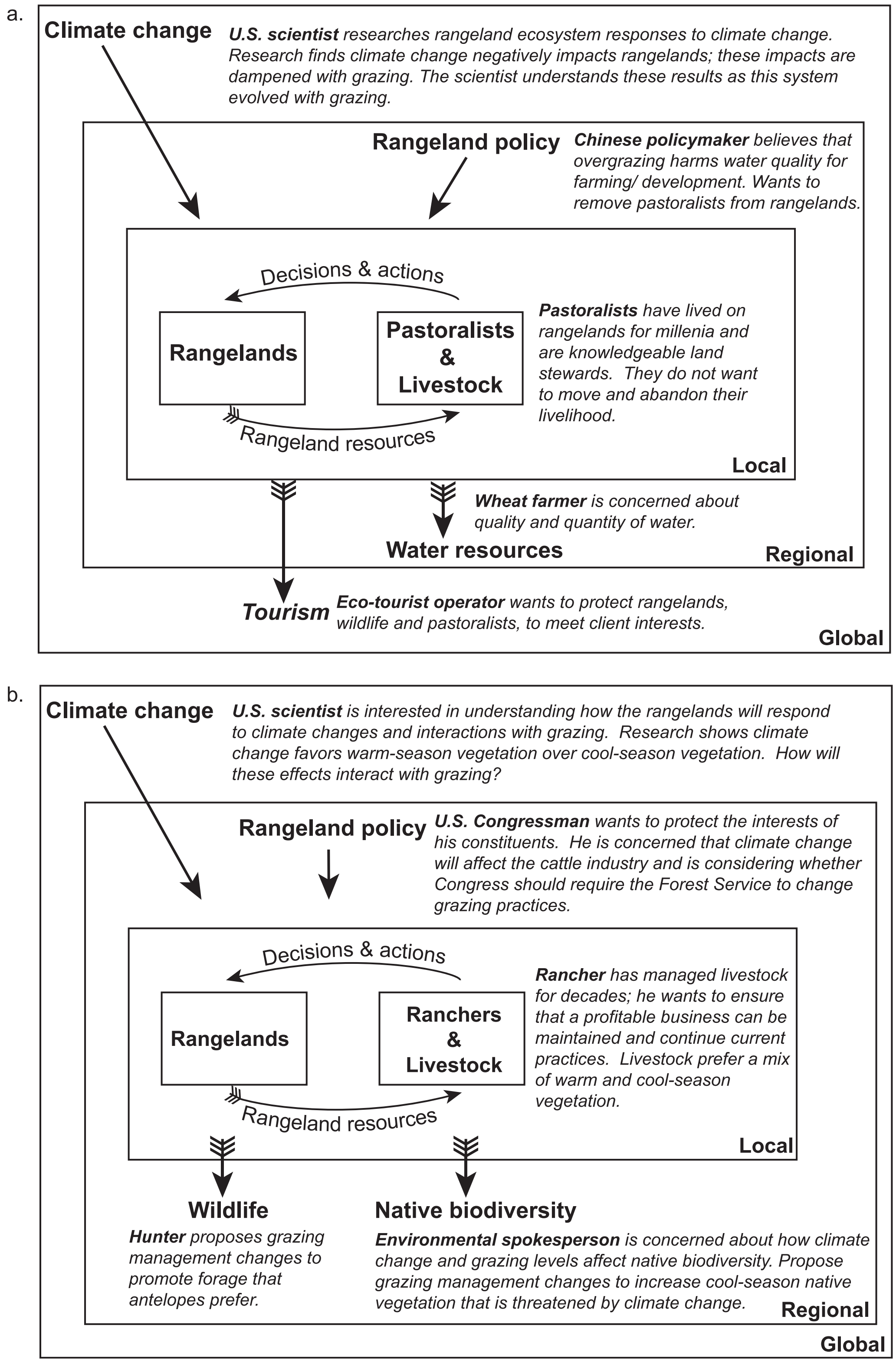

FIGURE 1: Conceptual diagrams of both case studies illustrate the complexity of the natural and biophysical systems and how the biophysical and social systems interact with each other. The diagrams also depict the factors or drivers (represented by plain arrows), such as climate change and grazing policies, that affect the rangeland biophysical and socioeconomic systems. Arrows with feathered ends represent the ecosystem services that come from these systems. The diagrams also show the different scales (local, regional, global) at which the system components, drivers, and services occur. (a) In the Tibet case study, there are several stakeholders interested in maintaining natural resources but for different reasons and with different perceptions of necessary management strategies. (b) Likewise, in the Western Great Plains (U.S.) case study, several stakeholders are concerned about natural resources; however, the

not ambient air temperature is responsible for the decreasing Adelie penguin populations in Antarctica. To participate in this lesson, students form "home groups" of five students. Each student represents one of five specialists: ornithologist, oceanographer, meteorologist, marine ecologist, or fisheries biologist. At the beginning of the lesson, all of the experts meet in their "specialist groups" and examine a set of data (quantitative and text). Each group must consider how the ecosystem of the Antarctic Peninsula has changed over the past 50 y after analyzing and discussing provided data sets. They must examine data relevant to their "specialist groups" and make inferences about patterns and trends. Then, "home groups" reconvene, and together they must pool their knowledge to determine the relationship between their individual data sets and the case of the decreasing Adelie penguin population.

ACTIVITY

We implemented our activity in three undergraduate science classes at our institution: a science pedagogy class for preservice science teachers (students majoring in biology, chemistry, or physics the semester prior to student teaching); a natural resource management class; and an environmental science and sustainability class. The class meeting time for all three of these courses was about 2 h—the length of time ideally needed to implement this lesson. The activity can be presented over two 1 h class periods as well. We obtained institutional approval to collect student data, and all students enrolled in the courses consented to have their pre- and postresponses analyzed. One of us is the instructor for the science pedagogy class; two other coauthors were present to record observations. Another one of us taught both the natural resource and environmental science courses; again, another coauthor was present to record observations during this activity. The instructors for these three courses have taught their respective courses or similar ones for several years (6–7), and both have PhD degrees in ecological life sciences.

Participants

In total, 44 students (29 men and 15 women) participated in this activity. The consenting science pedagogy participants included 6 men and 4 women whose majors were physics (2), chemistry (3), biology (4), and math (1). The consenting participants in the natural resource management class included 15 men and 6 women whose majors were natural resource management (5), rangeland ecology (12), forestry (1), anthropology (1), and international exchange (1). The consenting participants in the environmental science and sustainability class included 8 men and 5 women whose majors included ecosystem science and sustainability (6), watershed science (1), forestry (1), fish, wildlife, and conservation biology (1), and international exchange (4). The majority of the students participating overall were upperclassmen (37); however, some freshmen and sophomores also participated (7).

Sequence of Activity

None of the students in the three courses received any explicit instruction on climate change prior to the implementation of the activity. However, all students acknowledged having discussed or read about climate science in their other courses during their studies at our institution. Students were randomly assigned one of the two case studies to study, although they had access to both one-page information sheets. These were handed out in class or posted on each course's respective electronic blackboard pages. Each case study description began with a one-page information sheet with three short response prompts. These supplemental materials are available in the online version of the journal or at http://dx.doi.org/10.5408/13-070s1, http://dx.doi.org/10.5408/13-070s2, http://dx.doi.org/10.5408/13-070s3, and http://dx.doi.org/10.5408/13-070s4. These prompts were designed to be similar to one another across the two scenarios but were modified for each case study. Students read the information sheets on their own and submitted their responses through the electronic blackboard as homework before the class period during which the activity was conducted.

When class began, students were asked to sit on different sides of the classroom based on their case study (TP or WGP). Within these groups, students randomly selected stakeholder fact sheets (supplementary documents). Within each home group for each case study, there were five separate stakeholders (TP: pastoralist, Chinese policy maker, ecotourism operator, wheat farmer downstream, and scientist; WGP: rancher, U.S. congressman, environmental spokesperson, hunter, and scientist; Table I). In the science pedagogy class, there was exactly one student per stakeholder. Within the environmental science class, there was one stakeholder (scientist) in each home group for which students doubled up because there were not enough extra students to form a separate home group. In the natural resource class, there were two students who each played the same stakeholder role. In this class, we asked students who had selected the same stakeholder fact sheet to meet separately for about 10–15 min so they could discuss their position and review the empirical data included on their fact sheet before convening with their separate home groups.

The instructors and class observers circulated amongst the students, who sat in circles to discuss their case study. It was explained to students that the accompanying evidence (in the form of diagrams, maps, tables, figures, or graphs) was to help inform them of what concerns each stakeholder might have. We have listed examples of empirical evidence that instructors may want to use (supplementary documents); however, we encourage instructors to determine how best to supplement the stakeholder descriptions (including the option of not asking students to examine primary research data). We asked students to recognize that not all stakeholders might have access to the particular data we provided because we almost exclusively drew examples from primary research journal articles. When students needed help interpreting a figure or graph, we asked them to first discuss their questions with the group. Often students

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socio-political-economic system is notably different. In the U.S. case study, policy makers often listen to ranchers' interests and are dependent on their support.

TABLE I: Stakeholder roles for each case study home group.

Tibetan Plateau Home Group	U.S. Western Great Plains Home Group
Pastoralist	Rancher
Policymaker	U.S. congressperson
Ecotourism operator	Environmental/wildlife coalition spokesperson
Wheat farmer along the Yellow River	Hunter
Range scientist	Range scientist

were able to help each other; however, in other cases, we provided guidance on making sense of the graphs.

After students studied their own fact sheets (~15 min), they met as a home group for about 20–30 min. Then the whole class reconvened for a class discussion. Each group first described their stakeholders and their respective roles and evidence to support their claims about the rangeland management case study. Each group also described their group dynamics and the potentially competing interests and concerns of the individual stakeholders in their case study. This took about 20 min in each class. The instructor took notes on the board as comments were made. Finally, for the last 30 min, the class discussed how the two case studies were similar or different [see Fig. 1(a) and 1(b)].

EVALUATING THE CURRICULUM

Two data sources were used to evaluate the curriculum: students' pre- and postactivity written assessments and classroom observations/discussions. These data were used to ensure that our learning objectives were met and that our materials were appropriate and clear for undergraduate natural and physical science majors.

All students submitted pre- and postassessments electronically, which were graded for completion grades. For the TP case study, students responded to three prompts regarding whether pastoralists should be required to leave the Tibetan Plateau due to concerns about overgrazing livestock (supplementary documents). For the WGP case study, students responded to three prompts regarding whether ranchers should alter their livestock management practices, also due to concerns about overgrazing under a changing climate (supplementary documents). Each of the 44 students submitted two sets of responses (pre and post).

All responses were coded for the following characteristics using content analysis (Carley, 1990; Stemler, 2001). Five randomly selected student responses were read by three of the team to ensure that the content codes selected were appropriate for the types of responses. We then coded all pre- and postactivity written assessments for the following content: (1) types of evidence (presented scientific data, personal knowledge, personal experience, beliefs, or none); (2) presence of systems-thinking (natural science only, social science only, both, or none); and (3) location of system(s) they referenced in their case study assessment (WGP only, WGP plus other system, TP only, TP plus other system, or both WGP and TP). Because student responses ranged across all of these categories, our sample size was not large enough in any of the categories to conduct any statistical analyses.

One of us coded all 88 assessments, and two others read and coded 30 of these to ensure trustworthiness of our findings. The three coders initially met to read, code, and discuss five students' responses (10 assessments). Once we agreed upon our coding scheme, we coded separately. Our overall inter-rater coding reliability was around 90%. Although this activity was not intended as a research study, we wanted to ensure reliable coding methodology to evaluate our curriculum.

RESULTS

We found that all three of our learning objectives had been met. Students recognized that (1) there are multiple stakeholder perspectives that must be considered when making decisions regarding climate change; (2) both scientists and nonscientists need relevant evidence to make informed decisions about mitigating and adapting to climate change; and (3) decisions and stakeholders vary across cultural and geographical contexts despite having overlapping concerns.

Written Assessments

First, all students expressed the concerns of more than one stakeholder in their final assessments. Because the prompts asked students to consider the perspectives of different stakeholders, student responses often referred to a few different stakeholders. We found that 36% of the students did not describe any system (natural or social) in their pre-assessment responses compared to 64% that did (Table II). However, after participating in our activity, 84% of the students indicated systems-thinking in their post-responses, of which over half (56%) described the complexity of natural and social systems in response to climate change.

Second, only 11% of the pre-assessments included unsupported claims, and after the activity, only 4% of the postassessments included unsupported claims. The majority of the claims were supported by a combination of different types of evidence, including personal knowledge, personal experience or experiences from the class discussion, data presented as part of the activity, and beliefs (most often about the importance of consensus building before making or enforcing policy that impacts social and natural systems). We were pleased that for both the preservice teachers and the natural resource students, more students made data-supported claims on the postassessment than before the activity. This makes sense because the data were easily available during the activity. Moreover, students overall used data to support the positions of all of the stakeholders. In other words, students did not just use scientific evidence to support the perceived perspective of the scientist.

TABLE II: Student responses on pre- and postassessments.

	All Students		Science Pedagogy		Natural Resource Management	
	Pre	Post	Pre	Post	Pre	Post
Type of evidence used to support claim						
Scientific data	3	12	1	4	2	8
Personal knowledge	23	24	5	6	18	18
Experience	13	14	3	3	10	11
Beliefs	16	21	5	3	11	18
None	7	3	1	1	6	2
Systems thinking						
Natural only	4	5	0	0	4	5
Social only	3	2	1	0	2	2
Both	12	14	3	4	9	10
Neither	11	4	4	4	7	1
Location referenced						
WGP only	5	7	0	1	5	6
WGP plus other	15	7	6	3	9	4
TP only	4	9	0	0	4	9
TP plus other	12	7	4	4	8	3
Both WGP and TP	3	4	0	0	3	4

Third, during our class discussion, students in all classes compared the two case studies; however, we found that students were less likely to refer to other case studies on the written postassessment. We thought it was interesting that students who referred to other cases or examples tended to on their pre-assessment responses more than on their postassessments. For example, 27 students described other examples of ago-ecosystems along with one of the two, featured case studies on their pre-assessments compared to only 14 descriptions of other examples on the postassessment responses.

Classroom Discussion and Observations

Interestingly, very similar comparisons between the two case studies were described in all three classes. In all three classes, the Tibetan case study was compared to the experiences of Native Americans in the U.S. in particular those who lived and hunted on the Western Great Plains. Students explained that political treaties forced indigenous Americans to settle on reservations and restrict their hunting of wild bison. Students expressed a concern that government decisions to relocate Tibetans without indication of using evidence to inform their decisions would result in the loss of cultural ties to the land, as they described has happened in the U.S. It is important to note that we explained to our students that it is difficult to find the evidence that policy makers use to inform their rangeland management decisions. All three classes discussed the important distinction between the political and economic contexts of the two case studies (Fig. 1). Tibetan pastoralists live a subsistence lifestyle and have limited political voices under the current political system. On the other hand, American ranchers are engaged in agribusiness and generate profits through ranching. They have the ear of politicians for whom they choose whether or not to vote. Students in all three classes expressed that they had not thought about these subtleties until they participated in the activity.

Finally, all three classes spent several minutes discussing two stakeholders in particular, the wheat farmer in China and the hunter on the Great Plains. These stakeholders were developed to represent those who are indirectly impacted by livestock management decisions. After differences were identified, students decided that these two were actually quite similar to one another. Both of these stakeholders need resources (i.e., water or grasses for foraging antelope), and they both generate revenues for their regions (i.e., crop harvests for export or hunting tags and licenses that are often quite costly), and importantly, these practices will be dependent on the effects of climate change.

Our observations indicated that our three broad learning objectives were met. Participants identified the similar impacts of climate change on agrarian practices (locally and globally) but also recognized the importance of contextual differences. These include that: (1) it is important to recognize the multidimensionality of managing rangelands within the context of a changing climate when different stakeholders' perspectives are considered, (2) decisions cannot be made without relevant evidence, and (3) maintaining the ranching/pastoral way of life in the face of climate change will require adaptation, learning, and adjustments (e.g., the need to build resilience). However, we did not expect such a lengthy discussion on the importance of stakeholder communication (e.g., between policy makers and ranchers) if any type of consensus is to be formed. It is important to note that in the real world, finding common ground around complex issues can difficult to achieve, and so it is not always realistic to expect to reach consensus. Participants explained that not only must stakeholders communicate with one another, they must find common language and relevant evidence.

CONCLUSIONS AND FUTURE IMPLEMENTATION

In general, the conclusion of all three classes was that either pastoralists or ranchers should maintain their means of livelihood but would require assistance in modifying their practices. Many students maintained their pre-assessment decision of recommending changes in rangeland management practices, or not, on their postassessments; however, we found that many of these students already exhibited a systems-thinking approach to the issue. These students explained in their writing that it is typical for human behaviors to adapt to changing environmental conditions. This is, essentially, the practice of ''resilience,'' in which a system changes and adapts to external shocks and disturbances but maintains its essential structure and function (Walker and Salt, 2006). Resilience to climate change is often a goal that researchers and managers identify when discussing how to sustain human–environment systems in the face of climate change (Chapin et al., 2010).

In addition, students all agreed that consensus amongst various stakeholders was necessary before any decisions about mitigating and responding to the effects of climate change were made. Students were unable to find obvious consensus amongst stakeholders, but they were able to identify information not provided but necessary to come to consensus. Although some students were more explicit in tying in evidence to support their beliefs that consensus is important, the number of respondents who did not describe any systems-thinking dropped by almost two-thirds after participating in our activity. The interdisciplinary nature of climate change science and the human–climate interaction lent itself well to the type of jigsaw activity described in this paper. Our case studies used an interdisciplinary framework that includes multiple disciplines, including the biophysical science (e.g., geology, agriculture, ecosystem, and atmospheric science) and the social science (e.g., political science, anthropology, and rural sociology) content areas. Linking these content areas to one another can add relevance to the science content students have learned about climate change; it illustrates the interconnectedness and complexity of the human–climate system.

We chose to use written assessments because of the range of content knowledge of our three groups of students. We argue, though, that writing assessments allowed students to demonstrate their content knowledge as well as their ability to make evidence-based claims (Balgopal and Wallace, 2009, 2013; Balgopal et al., 2011). By using forced-response multiple-choice assessments, instructors often miss opportunities to evaluate students' ideas about systems and the evidence they find valuable in supporting their claims. When we implement this activity again, we likely will ask students to carefully consider many types of evidence when writing their responses. We did not direct students to make evidence-based claims, and therefore, some students' answers were much briefer than others (i.e., some submitted only 3–4 sentences for each of the three prompts compared to others who submitted three well-developed paragraphs).

These case studies were developed to incorporate rangeland and agricultural science, yet this activity can be used with other case studies incorporating different content areas. For example, separate case studies around coastal flooding in Louisiana and Bangladesh could be developed to incorporate oceanography. The activity could be further modified for content-specific undergraduate courses by incorporating empirical evidence relevant to that discipline (e.g., changes in biotic diversity in response to elevated CO_2 levels or changes in revenue generated from ecotourism in areas susceptible to natural disasters). Different assessment extensions can be added so both individuals and entire groups can be evaluated.

Testing the lesson allowed us to evaluate and strengthen our curriculum materials. We first developed the case study stakeholder roles without any accompanying empirical evidence when we used the materials in an informal climate change symposium. For that venue, this was sufficient, since we did not know the participants' backgrounds, and we were able to present Power Point slides. Our primary objective was for participants to recognize the overlapping and unique issues of ranchers/pastoralists in different parts of the world contending with climate change impacts on agro-ecosystems. We recognized the need to integrate empirical evidence, however, for our own college science students, for whom we wanted to help with reading and interpreting data from primary journal articles. Identifying relevant data for each of the 10 stakeholders proved to be a challenging task, since we were drawing from the existing literature and not necessarily from our own studies. We encourage those who use our lesson to modify the accompanying data according to the level of their students. Second, after our first implementation of the revised stakeholder data sheets (in the science pedagogy class), we discovered that students greatly benefited from short descriptions of the graphs or tables that we had provided during class discussions. These notes from our class observations were formally included in subsequent implementations of the activity. It was clear from our observational notes that students used these descriptions when describing the graphs or tables to their peers during home group meetings.

Even when students understand the science behind climate change, they may not find it relevant to their lives (National Center for Science Education, 2012). Although climate science has begun incorporating human aspects of climate change into climate models (Jacoby, 2004), educators still wrestle with students and parents resistant to the data and scientific consensus around anthropogenic climate change, making it difficult to teach (Wise, 2010). However, bringing the human dimensions into climate change, and showing students how the impacts of climate change are relevant to their lives and to people and cultures that they care about, is an important way to engage them with the science and interdisciplinary aspects of climate change (Schweizer et al., 2013). If policymakers and the public are to be actively engaged in decision making grounded in science and balancing the needs of society and the environment, students must understand the complexity of the changes that occur in the Earth system, in addition to the socio-political-economic complexities. Further, making decisions about human actions to mitigate climate change requires weighing environmental and social/cultural impacts (Fig. 1). Within each geographic context, various stakeholders will weigh different trade-offs to make decisions.

One of the challenges in climate change science is that we know anthropogenic climate change is occurring, but there is uncertainty about exactly how it will be experienced in different parts of the world over time and the rate at which the changes will occur. Uncertainties regarding effects on biophysical and human processes and their interactions, in part due to the complexities of these systems, are problematic because they tend to encourage some people to discount climate change science. Responding to such complexities will require teams of people with diverse backgrounds and expertise with respect to these multidisciplinary facets. We need leaders who are trained to work well in diverse, interdisciplinary teams and a populace that understands the complexities of the challenges we face and the difficulty of meeting the needs of all stakeholders. Curriculum activities such as the one we describe in this paper will help provide the foundation of understanding and skills needed for future success.

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SUPPLEMENTARY MATERIALS

The following documents are available online at http://dx.doi.org/10.5408/13-070s1, http://dx.doi.org/10.5408/13-070s2, http://dx.doi.org/10.5408/13-070s3, and http://dx.doi.org/10.5408/13-070s4.

Tibetan Plateau Case Study and Stakeholder Descriptions

Western Great Plains Case Study and Stakeholder Descriptions

Tibetan Plateau Case Study Stakeholder Student Handout

Western Great Plains Case Study Stakeholder Handout