A Climate Change Course for Undergraduate Students

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ABSTRACT

For the past 10 years, a climate change course has been offered in a large Midwest university. This course has been focusing on improving college students' scientific knowledge of climate change and human interactions using historical evidence as well as improving their information literacy in science through a course project that requires students to prepare a group presentation and a paper about an example of historical evidence of climate change and human interactions. This study evaluates the course's impact on students' learning of climate change and human interaction and improvement of information literacy in science based on students' responses to several questionnaires and interview data collected through the academic year of 2009. Results show that even if individual students had a different level of background knowledge of climate change and human interactions before the course, their content knowledge improved through the course. The students agreed that the course positively affected their information literacy in science (climate change) and interest. However, they neither disagreed nor agreed that they learned science knowledge relevant to their everyday lives and current socioeconomic issues related to climate change. They also thought that their environmental behavior did not change much as a result of the course. © *2011 National Association of Geoscience Teachers*. [DOI: 10.5408/1.3651405]

INTRODUCTION

As public concerns about global climate change increase, climate literacy education for all students of all ages (K–16 and adult) has emerged as a critical issue. Clearly, classroom education within the nation's colleges and universities is an important dimension to an informed society concerning global climate change (Johnson *et al.*, 1997). However, a recently published survey of earth science standards across the United States indicate that only 20 states indirectly address atmosphere, weather, and climate concepts within their standards and eight states fail to adequately address these concepts (Hoffman and Barstow, 2007). Consequently, about 80% of American adults are heavily influenced by incorrect or outdated environmental myths in these critical issues (NEETF, National Environmental Education and Training Foundation, 2005).

What students know and understand about environmental issues will ultimately influence their environmental decisions. Climate literacy of college students is especially crucial as they will face situations that involve making decisions affecting the atmospheric environment in the near future. If they do not have a solid understanding about global climate change and human interactions, we cannot be assured that they will take appropriate preventive actions against this crucial environmental issue in their everyday lives or in political contexts. Despite the necessity for a climate course for college students, there is a lack of good models for climate change courses for college student addressing these critical issues. Even worse, few studies show any evidence of the impact of the climate change course on student learning and their environmental behavior (e.g., Rebich and Gautier, 2005).

Most climate change education for college students has been done through introductory courses offered for general college students. Because most of the audiences are not familiar with climatology and meteorology, the courses focus more on teaching general concepts of weather and climate than climate and human interactions. Also, because the courses are often quick to present current climate change evidence and political debate about increasing carbon-dioxide, they sometimes exclude the scientific evidence we have about past climate changes and their interactions with ancient and modern human society.

Connecting climate change with human society is not easy work because it requires systemic understandings of two ways of interactions between climate and humans. There has been a debate about the magnitude of human impact on our current climate as well as human society's response to the climate change. However, it is an ongoing debate based on how much scientific evidence we have of current climate change (global warming) and how much human societies' responses will affect global and local climate change. The evidence of past events of human society and climate change can show one dimension of this complex interaction, which is how human society is susceptible to climate change. It also can help students understand a whole cyclic feature of these events and help them to predict future response of human society based on their understandings of current scientific evidence.

For the past 10 years, a climate change and human history course for undergraduate students has been offered in a large Midwest university. This course has focused on improving college students' scientific knowledge of interaction between climate change and human society using historical evidence of climate change and human history. This course also focuses on helping students improve their information literacy in science through a course project that requires students to present and write about specific historical evidence of interaction between climate change and human society. This study evaluates the course's impact on college students' learning about scientific knowledge of climate change and human interaction, as well as their perceptions about the course impact on their information literacy, based on students' responses on several questionnaires, interviews, and classroom observation

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data collected through the academic year of Spring 2009. As this study employs a formative evaluation study (Fitzpatrick *et al.*, 2004), its purpose is not only to provide evidence of the impact of the course on their learning about scientific knowledge and literacy but also to provide evidence on student participants' perceptions on course impact on their information literacy in science and environmental behavior, and to find positive ways to improve the course in general.

CLIMATE CHANGE EDUCATION FOR COLLEGE STUDENTS: WHAT DO WE NEED TO FOCUS ON?

Understanding Climate Change and Human Interactions

Global climate change is a multidisciplinary topic that should be addressed by connecting various disciplines such as science, mathematics, and engineering (e.g., Schnittka, 2009); social science (e.g., Andersson and Wallin, 2000); and literacy. Even within the science disciplines, the topic of global climate change integrates science concepts using chemistry, physics, earth science, and environmental science (Fortner, 2001). Therefore, studies about global climate change education are broad in terms of their disciplinary content and instructional design.

From the perspective of science education, studies about global climate change education for K–16 can be categorized into two broad groups: (1) instructional design to improve students' science literacy, scientific process, or inquiry skills using the content of global climate change and (2) research on students' conceptual understandings of global climate change. The studies in the first group show that the ability to interpret scientific data and connect the data to real-word situations is important in order to understand the content of global climate change, and more importantly, instructional strategies to improve these skills must be specifically addressed (e.g., Schnittka, 2009). For example, in a study of global climate change education for urban high school students, Rule and Meyer (2009) suggested using concrete and manipulative data sets as teaching materials and using interesting and real-world topics for the students to improve their ability to interpret graphs as well as content knowledge.

The studies in the second group explore students' conceptual understandings of global climate change by examining misconceptions or mental models of greenhouse gas, ozone depletion, or climate system structure (e.g., Bostrom *et al.*, 1994; Boyes *et al.*, 1993; Boyes, 1995; Dove, 1996; Fortner, 2001; Osterlind, 2005; Sterman and Sweeney, 2007; Summers *et al.*, 2001). These studies show that students have many misconceptions about the causes of global climate change. More importantly, these studies also suggest that students need a conceptual understanding of complex climate systems to understand the effect of global climate change on society. Conceptual understandings of global climate change must demonstrate the ability to think of the earth's climate as a system such as the stock and flow of CO2 in the system and the time scale of interaction of CO2 and other earth systems. Sterman and Sweeney (2007) argue that many advocates of global warming are delaying action until there is more evidence that warming is harmful, which they called the "wait and see" policy because they do not understand a simple climate system structure or stock and flow structure. They found that many highly educated graduate students in their study believe temperature responds immediately to changes in CO2 emission or concentration and even more students believe that stabilizing emission of CO2 near current rates would stabilize the climate. In short, students need the ability to think about climate as a system beyond basic content knowledge of global climate change.

Recently, along with efforts to understand complex natural phenomena, the effort to develop frameworks for improving the public's earth and environmental knowledge has increased. One of the leading programs for climate literacy education, the CLN (Climate Literacy Network, 2009), created a climate literacy framework as the following list. This list shows what climate principles and concepts are necessary to understand and communicate about climate science:

(1) Life on earth has been shaped by, depends on, and affects climate;
(2) We increase our understanding of the climate system through observation and modeling;
(3) The sun is the primary source of the climate system;
(4) Earth's weather and climate system are the result of complex interactions;
(5) Earth's weather and climate vary over time and space;
(6) Evidence indicates that human activities are impacting the climate system; and
(7) Earth's climate system is influenced by complex human decisions involving economic costs and values.

This framework shows that a climate literate person needs both knowledge of Earth's climate system and an understanding of how human activities are influencing Earth's climate system. Unfortunately, research shows that college students do not have the necessary content knowledge to understand physical climate system and human interactions (Boyes, 1995; Dove, 1996; Summers *et al.*, 2001; Trend, 2001). Most college students are unaware that natural events could also cause climate change; for example, volcanic activity. They also have misconceptions about the characteristics of atmospheric composition and human interactions. For example, Summers *et al.* (2000) found that students do not understand how human activities increase the concentration of greenhouse gases or the feedback effect the increase of greenhouse gases may have on human life. These studies also show that many college students' misconceptions about atmospheric compositions and human interactions are exacerbated by their nonscientific beliefs about these topics. Boyes (1995) found that students believed that ozone layer depletion as a form of large scale pollution related to the acid rain, greenhouse effect, and marine pollution. Dove (1996) also found that students believed that the greenhouse effect was the result of ozone layer depletion. Thus, understandings of physical climate systems and atmospheric components should precede the understandings of climate change and human interactions.

Understanding climate change and human interactions also requires the ability to think about earth systems interactions on many scales of time and space (Dodick and

Orion, 2003; Orion and Ault, 2007; Trend, 2001). According to Trend (2000, 2001), a personal mental framework of geological time is very important for understanding earth system events such as climate change. Trend (2001) found that college students do not have a concrete understanding of prehistoric time. Correct conception of geological deep time is important to understand and examine the inter-relationship between the climate change and human society. There has been increasing archaeological evidence that climate change and resulting environmental change has affected past civilizations (e.g., Brenner *et al.*, 2002) and notable events, such as the origins of rice domestication (e.g., Crawford and Shen, 1998; Jiang and Liu, 2006). Without understanding of geologic deep time, it is difficult to understand and to evaluate the inter-relationship between climate change and human society.

Understanding of geologic time is also related to the understandings of the motions of celestial objects (Earth–Sun–Moon) (Dodick and Orion 2003). Without understandings of geologic time, college students are also uncertain about how the inter-relationship between Sun and Earth affect long- and short-term climate change, as well as the mechanism of energy exchange between the Sun, Earth, and space (Summers *et al.*, 2001), and how this mechanism affect climate change over time. It is difficult to understand a complete climate system in terms of space because many concepts in climate systems are not visible or are difficult to see as a complete system or structure (Callison, 1993).

The primary purpose of the course presented in this study was to improve students' conceptual understandings about the physical climate system and the interactions between climate change and human society within the context of geologic time and space. In the first half of the course, we tried to improve students' understanding of geologic time and climate systems by addressing scientific facts and evidence of natural climate fluctuation in different geologic time scales. In the second half of the course, we used historical evidence of regional and global climate change and how the regional and global climate change affects human society in different aspects such as agriculture or the rise or collapse of an empire in different regions. For example, we examined how regional climate change (monsoon oscillation, flood, droughts) affected domestication of rice by using both scientific evidence and the archaeological evidence of local climate change. We also addressed how the period of global warming that occurred from roughly 200 BC to 400 AD was related to ancient human societies, such as Roman Optimum and how the Empire's expansion was affected by a shift in climate regimes. By examining the differences between regional and global climate change and its relation to human society, we also tried to improve students' understanding of earth system interactions in different spatial scales. We did not specifically address the current debate on humans' impact on the global climate change or if it is part of natural climate fluctuation because the most important purpose of the course was to improve students' ability to examine scientific information about climate change and its relation to human society using historic and archaeological evidence. However, we had many in-class discussions about the current debate on natural climate change, human impact on climate change, and possible outcomes of climate change on society by using the most recent articles about scientific evidence of historic climate change and its regional and global causes.

Information Literacy in Science

Currently, human influences on climate change are one of the most important issues that have come up frequently in political debate. Judging and evaluating the political debate about human influence on climate change requires not only some familiarity with scientific knowledge of climate change and human interactions but also, more importantly, the ability to find and evaluate the scientific information and to understand the process of how the scientific knowledge of climate change and human interactions have been accumulated and presented in public. Thus, the secondary purpose of the course was improving students' information literacy in science using the topic of climate change and human interactions.

In his chapter on scientific literacy in the recent *Handbook of Research on Science Education*, Roberts (2007) identifies two approaches (Vision I and Vision II) of generating conceptions of scientific literacy. The first approach (Vision I) envisions literacy within science and he argued that this approach is taken in producing Benchmarks for Science literacy (American Association for the Advancement of Science, 1993). The second approach (Vision II) envisions literacy within situations in which science has an important role, such as decision-making about socioscientific issues. He calls this second conception of science literacy as *literacy about science-related situations* (p. 730). Based on Roberts's (2007) second conception of scientific literacy, science literacy could be defined as the ability to find the scientific information, think, and critically evaluate the information and present their opinion based on their findings. According to Hazen (2002), these abilities are more aligned with the ability to use science than being able to do science. In today's information society, the ability to use science is as important as the ability to do science to be a scientifically literate citizen.

In general, the ability to use information is called *information literacy* in the literature. According to the American Library Association (ALA), "information literacy is a set of abilities requiring individuals to recognize when information is needed and have the ability to locate, evaluate, and use effectively the needed information" (2000, p. 2). Information literacy competency is highly important for students in science disciplines who must access a wide variety of information sources and formats that carry the body of knowledge in their field [ACRL (Association of College and Research Library, 2006)]. According to ALA (2000), an information literate individual is able to:

- determine the extent of information needed;
- access the needed information effectively and efficiently;
- evaluate information and its sources critically;
- incorporate selected information into one's knowledge base;
- use information effectively to accomplish a specific purpose; and
- understand the economic, legal, and social issues surrounding the use of information, and access and use information ethically and legally.

Information literacy is common to all disciplines (ALA, 2000, p. 2) but is not the same in all disciplines

(Laherty, 2000). Librarians tried to define information literacy in science in response to the increased call for information literacy instruction in colleges and universities (e.g., Laherty, 2000; Welborn and Kanar, 2000). As a result, information literacy standards in science-related fields were developed recently in view of a wide variety of information and rapidly changing nature of science disciplines (e.g., *Information literacy standards in science, engineering/technology* [ACRL, 2006]). There is correlation between Roberts's (2007) second conception of scientific literacy, "*literacy about science-related situations*" (p. 730), and information literacy in science. However, there has been no consensus on the definitions of information literacy in science in these standards and what should be assessed to measure students' information literacy in science. Thus, the research of assessing information literacy in science is still in its infancy.

Even in science literacy literature, there is no consensus about what we need to assess to determine students' current status of scientific literacy (Roberts, 2007). Most of the assessment of science literacy is based on scientific knowledge and attitude, which is Roberts's (2007) first approach (Vision I) of generating conceptions of science literacy (Roberts, 2007). What should be considered to measure students' *literacy about science-related situations*? In his recent article based on literature review of science literacy, DeBoer (2000) argued that "scientific literacy should be conceptualized broadly enough for individual classroom teachers to pursue the goals that are most suitable for their particular situations" (p. 582). In other words, scientific literacy needs to be understood as a goal of science learning in specific situations and contexts. In the specific context of this course, we defined a course purpose as what students need to possess lifelong skill of finding information they need. There is no valid assessment of measuring students' information literacy in science—specifically, climate change and human interactions. For this reason, we tried to study students' perceptions about the course impact on their skills and attitudes related to finding scientific information about climate change and human interactions rather than assess their improvement of information literacy in this area.

COURSE DESCRIPTION

Based on literature about college students' knowledge and conception about climate change and science information literacy, the course was set up with two main purposes: (1) improving college students' knowledge of climate change and human interactions and (2) improving their science information literacy and attitude toward climate change and human interactions. For pursuing the first purpose, the course content was structured with two main units; the first unit (half of the course) was about physical climate systems, and the second unit (other half of the course) examined the inter-relationship between the natural environment and human society. The second purpose was pursued mainly by students' team project, which was to create a team poster presentation and paper using a topic related to climate change and human interactions.

The first half of the course is split between (1) learning about the patterns and causes of climate change and (2) a survey of proxy records of past climate and environmental changes and the limitations of these proxy records. In learning about the patterns and causes of climate change, we looked at what we know about the patterns of past climate changes and their causes. We started with the general overview of climate change and human activities and uncertainties in science (proof and falsification, coincidence and causality) to give students a big picture of the concept of climate change and human interactions. In order to better understand how different processes can alter climate, we also devoted some time to learn how the modern climate system operates. Then, very long term patterns of climate change (the entire Cenozoic or the last 65 million years) to decadal or semiperiodic very short term climate changes (drought cycles in the Great Plains, El-Nino) were introduced; then what we know or do not know about the causes of these observed climate changes are explained. During the period of learning about proxy records and the limitations of these proxy records, we dealt with different proxy records of past climate changes (e.g., fossil evidence, sedimentary evidence, isotopic evidence, and historical evidence and instrumental records). We also dealt with the advantages and the limitations of methods of dating proxy record (e.g., radiometric dating, incremental dating, and age equivalence). In addition, we visited a paleolimnology laboratory at the university that has maintained lake sediment cores collected from different lakes within the state and all over the world. The students learned about how lake sediment cores are analyzed and used as proxy record of past climate using real lake sediments examples.

The second half of the course examined the inter-relationship between the natural environment and human society. Various past civilizations or notable events such as the origin of agriculture were examined in the context of climate and environmental change that were occurring at the same time and how humans responded to the change or even contributed to the change. Particularly, we reviewed examples from recently published science journal papers, including ancient Egypt (Pre-dynastic Period–Old Kingdom–Early Middle Kingdom); Indus Valley; the Medieval Climate Anomaly and the Little Ice Age (Norse Colony in Greenland, Maya, Chaco Canyon and Mesa Verde); and recent droughts (the Dust Bowl and the Sahels). The emphases of the first and second halves of the course together fulfill the Environment Theme described by Brenner *et al*. (2002) in Fig. 1.

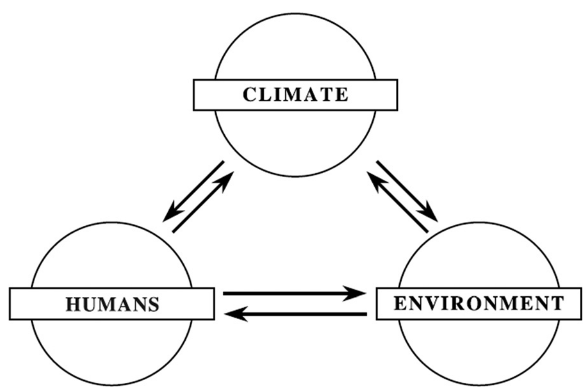

FIGURE 1: The environment theme: climate, environment, and human interactions by Brenner *et al*. (2002).

While there have been arguments about the necessity of improving college students' information literacy in science, there is little empirical research about actual strategies to improve it. The most common and effective strategy in the literature is to wed instruction in bibliographic resource to a course project in which students are simultaneously acquiring subject knowledge and direction from the professor (e.g., Brown, 1999; Stoan, 1984). The *team poster project* was designed to fulfill the purpose of improving students' information literacy in science. The project requires that students demonstrate their knowledge of climate change and human interactions using specific examples, as well as helping them think critically think through the evaluation of the knowledge, and finally improving their ability to effectively communicate using scientific evidence. After finishing the first half of the course, the course instructor introduced the team project topics and asked each team to choose one or two interesting topics. Teams were assigned on the basis of academic major and the number of postsecondary science courses taken. Each team chose a topic from the examples listed in Table I or any other topic if it was not covered by the course and was appropriate to the course content (such as domestication of various animals and other plants).

By the end of the course, students had organized the information into a coherent and visually attractive poster. The last 2 days of the course were structured for the team post presentations. Each team member gave a 10-min presentation describing their key findings. They also needed to prepare an abstract of their team project and three key questions that other students needed to answer during the presentation. After each presentation, other students asked questions about the topic and evaluated the presentation using a 4-point system (Poor = 0, Average = 1, Good = 2, and Excellent = 3). While preparing the presentation, each team member took the same set of information for their presentation and wrote individual term papers organized like published scientific (Earth Science) papers.

METHOD

This study employed a formative evaluation design (Fitzpatrick *et al.*, 2004), with the purpose of determining the impact of the course on student learning as well as suggesting ways to improve instruction. Mixed methods were used to answer the different research questions. Content knowledge questionnaires were administered two times (pre and post) during the course to measure students' content knowledge of climate change and human interactions. Student interviews, classroom observations, and an end-of-course survey were conducted to find out students' perceptions about the overall course, as well as the impact of the course on students' information literacy in science, attitude, and environmental behavior related to climate change.

TABLE I: Climate change and human interactions team poster topics and main questions.

Topic	Question
Peopling of the New World	When and how did humans migrate into North America (and Central and South America) from Asia? Critical time period: 38,000 BP to 10,000 BP. What were their motivations?
Collapse of the Akkadian Civilization	Deals with role of climate in the Near East around 4000 BP and the fall of the Akkadian empire.
Collapse of the Hittite Civilization in Anatolia	Hittites were powerful enemies to Egypt at the time of Ramses III.
Mycenae collapse	Refers to the fall of Mycenae civilization in Greece around 1200 BC and the role that climate variation may have played in it.
The Roman Optimum	Expansion and contraction of the Roman Empire and the possible relation to climatic shifts.
The establishment and abandonment of Cahokia (Mississippian culture)	The abandonment of Cahokia (ca. 650 CE to 1050 CE) is variously attributed to political instability, epidemic disease, and human/climate induced environmental degradation.
Fall of Chinese Dynasties	Did the fall of Chinese dynasties such as the Tang, Yuan and Ming have any relation to climatic events or primarily due to societal and political events?
Mongol invasion into central Asia and central Europe	Deals with the sacking of Baghdad (13th century AD) and repeated incursions of Mongol invaders into Europe. Was hyperaridity and lack of grass for horse grazing in Mongolia responsible for this event?
Domestication of wheat	Deals with the origin of cultivation and domestication of wheat in the Levantine corridor and the possible role of Younger Dryas.
Domestication of rice	Deals with the beginning of irrigation, cultivation and domestication of rice in the Yangtze Valley of China (and elsewhere?) and the possible role of Younger Dryas.
Domestication of corn	Deals with the selection, cultivation, and domestication of wild corn in Central America.
Domestication of potatoes	Deals with the selection and cultivation of wild potatoes in South America and its subsequent effect on the world events.

Settings and Student Participants

The course titled *Climate Change and Human History* was offered at a large Midwest university. The course was designed for general undergraduate students and open to all undergraduate and graduate students. Most of the students were traditional second and third year college students between the ages of 18 and 22. A total of 23 students successfully finished the course. Table II presents student demographics in the course: There were 13 male students and 10 female students in the course. Their average GPA was in the range of 3.0–3.5. Eighteen students were in science or science-related majors and 5 students were nonscience majors. Thirteen students had taken one or two college level science courses from which they learned a little about climate change, from courses such as introductory geology, environmental science, and science policy courses.

Data Collection

Content Knowledge Questionnaire

The researcher created one content knowledge test item for pre- and postcontent knowledge tests. The pre- and post-tests were the same test and administrated both at the beginning and at the end of the course. Reliability, as Cronbach's alpha, is listed after each test. All students were encouraged to take the 19-item pretest during the first week of the course. The test contained multiple choice items that assessed both general knowledge about climate systems and the knowledge of climate change and human interactions (reliability $\alpha = 0.72$). The questionnaire items were developed and categorized based on important topics addressed in the class and reflected the knowledge actually required for the given topic areas. Seven general climate system knowledge items assessed scientific concepts related to the climate change such as time scale of climatic states or patterns, average temperature shift, and climate type. Five climate change and human interaction items focused on assessing important concepts of human history related to climate change using the real archaeological examples. The content validity of the questionnaire items were examined by other experts in climate change education. Both types of items were repeated on the post-test (reliability $\alpha = 0.72$) in same manner.

TABLE II: Student participants' demographic data ($N = 23$).

Variables	Demographic groups	Percentage
Gender	Male	56.5
	Female	43.5
Major	Science	65.2
	Nonscience	21.7
	Both (with minor)	13.0
GPA	2.5–3.0	21.3
	3.0–3.5	26.0
	3.5–4.0	52.7
College level courses students took before the course related to climate change	Introductory geology	21.3
	Environmental science	21.3
	Science policy	0.08
	Others	21.3

Interview

Seven student volunteers were interviewed face-to-face using a subset of questions from the survey to provide richer information about the impact of the course. Four interviews were conducted with one or two students. Each interview took approximately 1 h and was conducted during the last month of the semester to get students' perceptions about the entire course structure and curriculum. Some examples of interview questions were as follows:

- What did you expect to learn about climate change before you took this class?
- What is the most interesting topic in this class?
- How do you think about the content structure of this class? (see the syllabus)
- What did you actually learn about climate change in terms of your expectations?
- How does the team project affect your ability to find and evaluate climate change information and human interaction?
- Give examples of how this course has changed your thinking about climate change?
- What do you think is the course impact on your ability to access and evaluate science information about climate change and human interactions?

Classroom Observation

Seven classroom observations were conducted to catch instances of student learning. Classroom observations included two class sessions of the students' team poster project presentation at the end of the semester. To get consistent data, the classroom observations were conducted at 1- or 2-week intervals. The researcher made written descriptions during the observations and tried to describe the instructor's teaching strategy, interaction between the instructor and students, classroom climate, and relevance of content knowledge for the course topics and students' everyday lives.

Survey

Student completed a survey developed by the researcher at the end of the course. They were not required to take the survey as part of their course grade. The survey questions were grouped into three categories: (1) background information: questions regarding students' demographic background, GPA, major, related course previously taken; (2) course evaluation: students' satisfactions about the course content, management, course support, etc.; and (3) course impact: improvement of scientific knowledge, information literacy, and environmental behaviors as a result of taking the course. Each question was composed with subitems that sought students' agreement about the question. For example, the survey question, "How important is knowledge of the following for understanding climate change and human interaction?," included seven subitems: (1) scientific evidence of climate change, (2) climate change mechanisms, (3) temperature shift and climate change, (4) geologic time scale, (5) current natural disaster issues related to climate change, (6) archaeological evidence of human history, and (7) current political issues related to climate change. For each subitem, students were asked to check their agreement level. Students' agreement levels were measured by using 3-point, 4-point, and 5-point Likert systems (e.g., 5-point scale being Strongly disagree = 1, Disagree = 2, Neutral = 3, Agree = 4, and Strongly agree = 5). Along with the scale of the questions, students were also asked to write their suggestions and comments on each of the questions. In addition, survey questions also covered students' perceptions of change of their environmental behaviors such as recycling, use of mass transportation, and energy conservation. The questions on students' environmental behavior were modified from several surveys conducted nationally and internationally, such as environmental behavior surveys in NEETF.

Data Analysis

Quantitative Analysis—Content Knowledge Questionnaire

A multilevel model, hierarchical linear modeling (HLM), using longitudinal data was performed to identify the unique impacts of the course on students' learning of science knowledge of climate change and human interactions. We used the *HLM 6 Hierarchical Linear and Nonlinear Modeling* program (Raudenbush and Bryk, 2002) to analyze the students' content knowledge questionnaire. This analysis method allows us to determine any individual differences in the precontent knowledge test before the course. It also allows us to test statistical significance between the pre- and post-test results without ignoring missing data (Raudenbush and Bryk, 2002). HLM using longitudinal data has different structures compared to the typical HLM data structure. In longitudinal analysis, each student's longitudinal data (in this case pre- and post-test scores) (level 1) is nested in the individual student (level 2). Of the students enrolled in this course, 81% responded to the survey (17 out of 23). The surveys were analyzed both by simple descriptive analysis of participant response on 3-point, 4-point, or 5-point Likert scale items.

Qualitative Analysis—Interviews, Classroom Observations, and Survey's Written Responses

Interview transcripts (IT), classroom observation descriptions (CO), and students' written responses on the survey (SR) were collapsed into one data source and categorized based on the research questions. However, data on classroom observations served mainly for triangulation purposes to support the validity of the common themes. Qualitative analysis proceeded with initial descriptive codes being assigned to students' responses and interview transcript. Related codes were then grouped according to common themes: (1) students' learning of scientific knowledge, (2) improvement of information literacy in science, (3) changing attitudes and environmental behaviors, as a result of taking the course, and (4) course evaluation (satisfaction about the course content, activities, and final team project). Table III demonstrates exemplary statements coded as examples of the common themes. The coding was conducted independently by two researchers, including the authors. The inter-rater reliability in this coding was 86%. The interpretation of the classroom observation descriptions were also cross-examined with the instructor. This written data analysis focused on (1) looking for

TABLE III: Exemplary statements coded as examples of the common theme along with evidentiary words italicized.

Common themes	Examples
Learning of scientific knowledge	"The most interest thing *I learned is that Climate is affected by oceanic current and earth rotation*" (IT)
	I always knew a lot of the geology but in this class *I learned archaeological evidence of human history* (SR)
	I'm interested in *the topic of Norse and evolution of human* because I think it is more *interesting to learn* where we come from (SR)
Improvement of information literacy in science	"This course uses a lot of really recent research and information in graphs. She (instructor) talks a lot about controversial topics in the field today" (IT)
	It is good to learn the science behind the theory so that *you don't get confused by arguments in the media* (SR)
Changing attitude and environmental behavior	I *already recycled things* prior to the class (SR)
	I already tried a lot to conserve before I ever took this class, so the class had little effect but *it does reinforce my reasoning for conserving* (SR)
Satisfaction about the course content, activities, and final team project	"She (Instructor) is *very clear and concise in her presentation* so I feel that I understand pretty well even though some of it is very specific and advanced" (IT)
	Video on the Norse in Greenland was good and it is *easier for me to understand* (SR)
	I'm not a science major and *this course was too difficult for me* (SR)
	"*I really like the topics she (instructor) gave for the final project*. She did a lot of work to find *good topics* for the final project for each student" (IT)

TABLE IV: Descriptive data for students' content knowledge test at pre- and post-test.

	Mean	SD	Minimum	Maximum
Pretest ($N = 18$)	5.78	2.24	2	9
Post–test ($N = 18$)	7.17	2.87	2	11

variability and consistency in what students said about their perceptions of course impact on their learning and environmental behavior and (2) finding evidence for improvement of their knowledge, information literacy in science, and environmental behavior.

RESULTS

Students' Learning about Content Knowledge of Climate Change and Human Interactions

The primary purpose of the study is to know the impact of the course on students' understanding of content knowledge (climate system, geologic time, and relationship between climate and human history). The descriptive statistics of each test (pre- and post-test) are presented in Table IV. Even though five students were missing pre- and post-test (with the total number of the students taking this class being 23), it shows that the mean and maximum score at post-test increased compared to the pretest.

Knowing that the mean differences were statistically significant and there were significant differences between students' individual pretest scores, we conducted HLM. Through the HLM software, a homogeneous level 1 variance model was chosen based on the parameter number and deviance. The result using this model is presented in Table V. Students' average test score at initial status (pretest) (β_{00}) were 6.46 (the total of marks was 12 points) points, and the individual score at initial status (pretest) was significantly different between students. It showed that students had a different level of understanding about climate change and human interactions before the course.

The average growth rate of their test score (β_{10}) was 0.69 points per test. It means that on average, students' test scores were linearly increasing 1.38 points per test and it is statistically significant ($\alpha = 0.05$). The statistical result from HLM longitudinal analysis shows that regardless of their prior knowledge, on average, students gained some measurable knowledge about climate change and human interactions throughout the course.

In addition to their scientific knowledge gain about climate change and human interactions as the statistical evidence in Table V showed, we found that students' perceptions about their knowledge about climate change also increased. Table VI presents the results of students' perceptions about their scientific knowledge about climate change before and after taking the course. It appears that

TABLE V: Two-level hierarchical linear modeling result of statistical significance of individual differences at initial status (β_{00}) and average growth rate (β_{10}) ($N = 18$).[1]

	Coefficient	Standard error	T-ratio	df	P
β_{00}	6.4722	0.5248	12.333	17	0.000
β_{10}	1.3888	0.5394	2.575	17	0.020

[1]The result is significant at $p < 0.05$.

TABLE VI: Students' perceptions about their scientific knowledge about climate change before and after taking the course.[1]

	Before the course ($N = 17$)		After the course ($N = 16$)	
	Mean	SD	Mean	SD
Scientific knowledge about climate change	2.35	0.86	3.31	0.70

[1]The responses are based on a 4-point rating system (1= not good, 2 = about average, 3 = good, 4 = very good).

while most of the students rank their scientific knowledge about climate change about average before taking this course, they rank their scientific knowledge about climate change as good (above average) after the course.

In the interview analysis, we also found that the students agreed that the course covered important scientific knowledge about climate change as well as historic evidence of climate change using human history and archaeological evidence. Students who are not science majors said that the content was a little difficult to understand. However, they also agreed that using graphics and figures to present content from recent science articles was very helpful to understand the main ideas and the current climate change debate (IT). For students who are science majors, the course was interesting because they could connect geology knowledge to human history using archaeological evidence (IT). Thus, we can say that in addition to statistical evidence of students' content knowledge improvement, their perceptions about their scientific knowledge about climate change and human interactions also have been improved during the course.

Students' Perceptions about the Course Impact on Their Information Literacy in Science of Climate Change and Human Interactions

The course was also designed to improve students' information literacy in science using climate change and human interaction issues. During the second half of the course, students learned about science knowledge related to climate change and human interaction using scientific and archaeological evidence as well as by researching their own topic for their team projects. Along with the students' team project research, the instructor helped them to find appropriate resource (research articles, Internet resources, books, etc.). The instructor also tried to present the most recent information about the topics and debate related to the topics during the class. She also encouraged students to present and discuss their ideas about the topics during the class. Eight topics were chosen by eight groups of students: Domestication of Rice, Domestication of Corn, The Roman Optimum, The Peopling of the New World, The Ming Dynasty, Cahokia, Chaco Canyon, and Mycenae. The most common reason they chose the team project topic was their interest in the topic. Some students were interested in certain topics because of their familiarity with the topic or the relationship with their major. For example, one student whose major was Asian Languages and Literature chose The Ming Dynasty for her topic because she wanted to learn more about the historical and climatic factors that had affected the decline of the Ming Dynasty. She believed that if she could learn more about historical evidence of climate change in China, it would help her understand China's history for her major.

Using team project topics, the students searched for scientific information and evidence of how climate affected these events in human history such as how climate change affected domestication of rice, downfall of certain dynasties, or ancient human migration. For example, the Ming Dynasty team found that the end of the Ming Dynasty coincided with the coldest parts of the "Little Ice Age" using several historical as well as paleoclimatic records. They used a lot of literature dealing with the relationship between climate change, wars, and dynastic cycles in China. In their final short report, they concluded:

> Despite clear evidence suggesting the cooling did occur towards the final years of the declining Ming Dynasty, we hesitate in making climate change a more important factor than ineffective government by the kings and bureaucracy. It is important for modern societies to keep these historical periods in perspective as climate change threatens to disrupt international politics as we now know it.

This showed that they also critically thought about and evaluated the science information they found to make sound arguments for their ideas and make conclusions through discussion with their group members. Through these processes, they learned how a historical event could be presented scientifically using current scientific knowledge and evidence.

On the other hand, they also learned the fact that an historical event could be interpreted and presented differently by using different types of scientific and archaeological evidence. Figure 2 presents one of the examples of the students' final team project poster about the relationship between Roman Optimum and climate change.

In the group presentation on Roman Optimum and climate change, the students examined the political geography in light of climate geography. They not only examined three main climates that affected the region but also how climate change affected human society. They showed how climate change during the period affected growing wheat as well as supporting the political infrastructure of the Empire. Even if they concluded that there were other factors of the expansion of the Empire during the period,

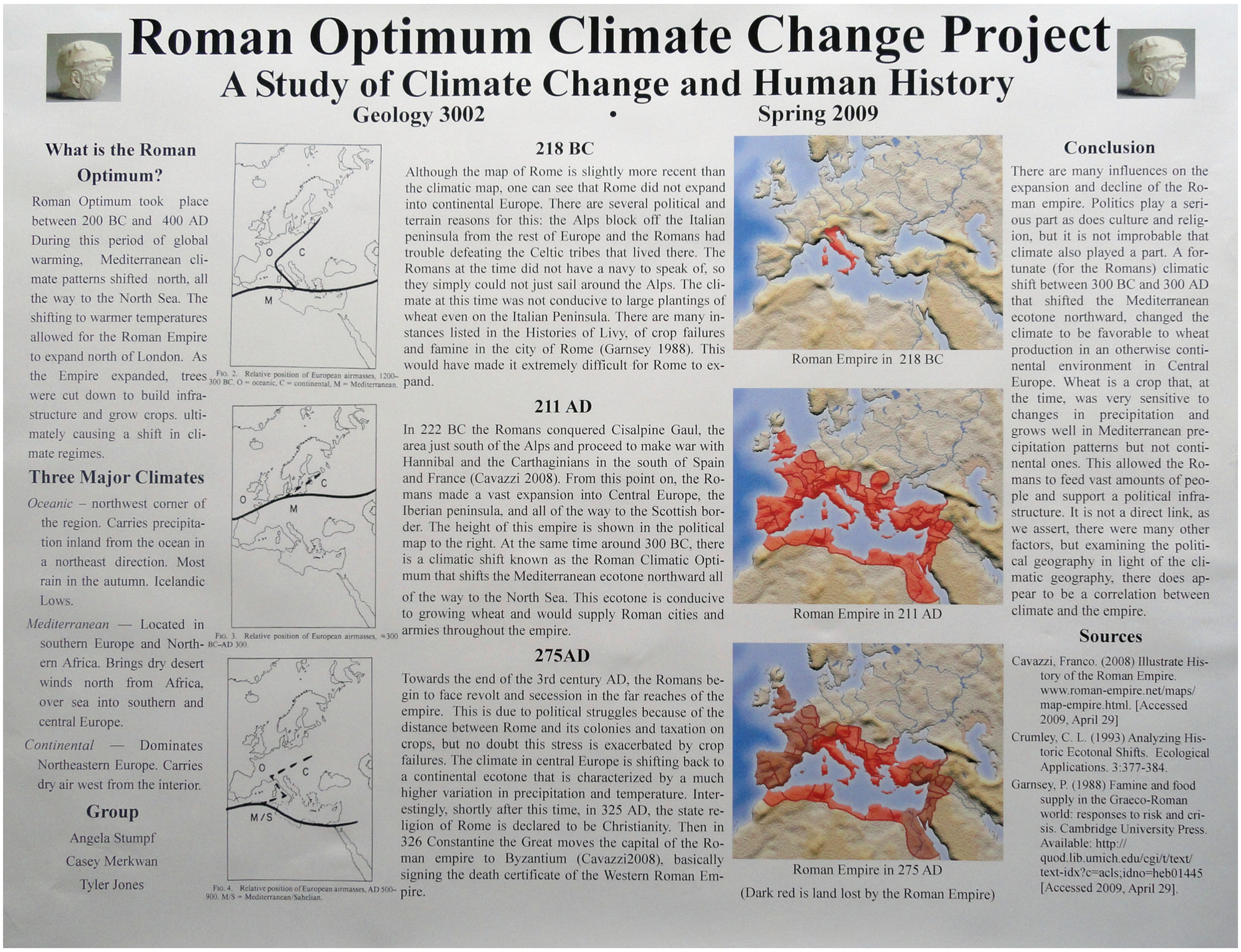

FIGURE 2: (Color online) A picture of students' poster about the topic of Roman Optimum and climate change.

TABLE VII: Students' perceptions about the course impact on their information literacy in science of climate change and human interaction ($N = 18$).[1]

Climate change literacy		Mean	SD
This course positively affects me to…	Think critically and evaluate information related to climate change	3.94	0.55
	Find scientific information to support my ideas	4.17	0.52
	Present my opinions related to climate change in public	3.76	0.75
After taking this class, I am….	More interested in climate change or other related issues	4.05	0.65
	Reading more articles, books, and news related to the climate change	3.76	.03
	More concerned about current environmental issues or natural disasters related to climate change	3.94	0.65

[1]The responses are based on a 5-point rating system (1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 =strongly agree).

they show the correlation of the climate and the Empire (CO).

During the final presentation, the students also used different types of graphs, tables, and figures to show different types of proxy data analysis result, archaeological evidence, and to present their findings more efficiently (CO). Through the process of gathering information using various sources, representing the information using different methods, and presenting their finding in front of the class, they also felt more confident using scientific information and resources to support their findings about the topics (SR).

Table VII presents students' perceptions about the course's impact on their information literacy in science of climate change and human interactions. It appears that students' perceptions about the course had a positive impact on their information literacy in science (ranged between point 3 and point 4 in 5-point Likert scale). While they did not strongly agree, on average, their perceptions about information literacy in science (mean = 3.93) located closely to point 4 (Agree). They especially agreed that this course positively affected their skills in finding scientific information to support their ideas (4.17) and made them more interested in climate change and human interactions (4.05).

During the team project presentations, each team presented their research about their team project topic. Each team member rotated to present certain parts of the presentation where they were in charge of finding and making arguments about the topic. Each team made a short abstract of their research and prepared three questions for their audience. Most of the students were highly engaged in the presentation and asked many questions about the presentation topic. It is important to note that most of students were very interested in their team project topic and wanted to learn more about it after the course. The team project experience seemed to be an important opportunity to improve their information literacy in climate change and human interaction issues in terms of encouraging them to find information, evaluate information, and make critical arguments about what they found. This opportunity can engage students in lifelong learning about this issue as well as improve their interest in climate change and human interactions.

Students' Perceptions about the Course Overall

Most of the students enrolled in the course because of their interest in the course topic and/or because of its relation to their major. One third of the students were taking this course primarily because it fulfilled a requirement for their graduation (30%). Regardless of their primary purposes for taking this course, we found that interesting topics for most students were related to archaeological evidences of human history and climate change such as the African rift valley and human beginnings, Maya, Norse in Greenland, and ancient Egypt. A few science majors said that the topics they found interesting were climate change mechanisms and proxy data analysis but for most students, human history and culture and the interactions between these and climate change were the most interesting topic during the course. This is also reflected in the students' responses to the topics they wanted to learn more about after the course. Most students answered that they wanted to learn more about how climate change affected ancient human societies. However, they also wanted to learn more about modern concerns about climate change or current issues related to climate change.

Because we did not address much about climate change related to current socioeconomic and political issues, we asked questions about whether they think current political issues are important in understanding climate change and human interactions with other key knowledge of climate change in the survey. As one of survey questions, we asked the students to rank how important the knowledge of the following list is for understanding climate change and human interactions based on a three-rating system (1 = not important, 2 = somewhat important, and 3 = very important). We also asked students to check what knowledge in the list they have learned from the course in the following question.

As Table VIII presents, it appears that students ranked most of the key knowledge close to *very important* than *somewhat important*, except two on this list: *Current natural disaster issues related to climate* (2.29) and *Current political issues related to climate change* (1.94). This result is parallel with the results of the second question about the knowledge they have learned. Only 37.5% of respondents said that they have learned about *Current natural disaster issues related to climate* and 12.5% of respondents said that they have learned about *Current political issues related to climate change*. As we expected, there is a possibility that they tended to say that the knowledge is not important to understand the climate change and human interactions because students thought they did not learn about the knowledge. However, we could say that most of the students thought that the other listed knowledge pieces are more important than these two knowledge pieces.

TABLE VIII: Students' rank of the importance of key content knowledge for understanding climate change and human interactions ($N = 18$).[1]

Key content knowledge	Mean	SD	Percentage ($N = 8$)
Scientific evidence of climate change	3.00	0.00	100.0
Climate change mechanism	2.94	0.24	87.5
Temperature shift and climate change	3.00	0.00	100.0
Geologic time scale	2.76	0.43	75.0
Current natural disaster issues related to climate change	2.29	0.58	37.5
Archaeological evidence of human history	2.70	0.46	100.0
Current political issues related to climate change	1.94	0.74	12.5

[1]The responses are based on a 3-point rating system (1 = not important, 2 = somewhat important, 3 = very important). Percentage = % of total responses who check the knowledge as they have learned learn from the course.

In addition to students' perceptions about their content knowledge of the course, we also asked a set of questions about students' perceptions of how the course impacted their environmental behavior in their everyday life. Table IX presents the set of questions and results of descriptive statistics. Even if there are little differences between items, students' ranking about the items located between points 2 (neutral) and 3 (well) and average ranking (2.58) is a little closer to point 3 than 2. Even if there was little evidence of positive impacts, it is hard to say that the frequency of students' environmental behaviors change much due to the course (2.58).

TABLE IX: Students' perceptions about the course impact on their environmental behavior related to climate change and human interactions ($N = 18$).[1]

This course positively affects the frequency of my behavior of ……… in my everyday life.	Mean	SD	N
Turning off lights and electrical appliances when they are not in use	2.70	1.10	16
Recycling things such as newspapers, plastics and cans	2.76	1.09	17
Buying recycled or biodegradable products	2.35	.93	16
Using a bike or the bus instead of driving my car	2.68	1.13	16
Taking to my friends or family about climate change and/or other environmental issues	2.70	0.98	16
Voluntarily participating in any environmental activity	2.31	1.30	16

[1]The responses are based on a 4-point rating system (1 = little, 2 = neutral, 3 = well, 4 = very well).

TABLE X: Students' perceptions about their learning of scientific knowledge relevant to their everyday life and current socioeconomic issues.[1]

Through this course, my……was improving	Mean	SD
Scientific knowledge relevant to my everyday life	2.80	0.94

[1]The responses are based on a 5-point rating system (1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 = strongly agree).

This could be linked to their perceptions of learning scientific knowledge relevant to their everyday lives presented in Table X. It appears that students' perceptions about learning scientific knowledge relevant to their everyday life is located between points 2 (disagree) and 3 (neither agree nor disagree).

It is interesting that students thought that the scientific knowledge they had learned in this course is not relevant to their everyday lives because the course dealt with a much larger context of climate change than they could experience in their everyday life in terms of time and space. Using scientific evidence about historical events could also affect their response. Most of the topics dealt with in this course as well as in their team projects were related to climate change and human activities in historical context, not in the current context. It is important to understand the big picture of climatic systems and how human interaction affects the change of the climate. However, due to the huge differences in terms of scale of time and space of climate change and human history, it is hard to connect the concepts to the short term time period and small space in everyday context. It was interesting that if students learned scientific knowledge based on scientific evidence of historical event, they did not think that the knowledge is relevant to their everyday lives even if the knowledge is very important to understand current natural events.

DISCUSSION AND IMPLICATIONS

This course offered in-depth content knowledge about climate change including general knowledge of climatology, proxy data analysis for reconstructing past climate change, and archaeological evidence about human reactions about climate change. A statistical analysis of students' pre- and postcontent test shows that regardless of their prior knowledge, on average, students gained some measurable knowledge about climate change and human interactions throughout the course. Students agreed that the course positively affected their information literacy in science and their interest in the topics. Especially, they agreed that this course positively affected their ability to find scientific information to support their ideas. They also became more interested in the issues of climate change.

The team project helped students to improve their ability to find science information, to evaluate the information, and to make sound arguments of their ideas. Especially, they argued that human society had not only been affected by natural climate change but also by other human-made systems such as politics, cultures, and religions. During the presentations, students also showed their ability to make sound scientific arguments and demonstrate how they arrived at the conclusion using different types of evidence. They asked questions and answered questions using examples they learned throughout the team projects. It also made students more interested in learning more about their topics as well as the topics presented by other groups.

However, students' rating of the course impact on the frequency of their environmental behavior change ranged between neutral and good. Even if there was little evidence of positive impacts, it is hard to say that the frequency of students' environmental behaviors changed much due to the course (2.58). Their agreement levels about the course impact on their science knowledge relevant to their everyday lives were also around neutral (neither disagree nor agree). We believe that there were three possible reasons for these results. First, the course did not address specific examples of the connection of how individual life style affects the environment, such as assessing personal CO_2 emission. As a result, for the students who were uncertain about how much their lifestyles affect the entire earth climate system, the course did not persuade them to change their life style. By demonstrating the relevance of lifestyle choices on greenhouse gas emissions, the course could improve students' awareness about environmental problems and assist students' value shifts toward environmental behaviors (Lezen, 2001). The second possible reason was (quite opposite with the first reason in terms of the impact of the course content) that learning about the uncertainties of human impact on current climate change might affect the students' reasoning of environmental behavior. Throughout the course, students learned about the uncertainty of human impact on current climate change and the possibility of natural fluctuation of it. Similarly, a survey result from 400 climate scientists around the world shows that these scientists are relatively uncertain about identifying human-induced CO_2 as the main cause of climate change (Bray and von Storch, 1999). Especially for the students with certain kinds of environmental behaviors, such as recycling papers or cans, the course did not motivate them to reinforce their environmental behaviors. The third reason was (more general) that regardless of the instructional approach or content, an individual's environmental behavior is difficult to change, especially if it is related to the convenience of their life style or money they need to pay for the lifestyle change. For example, Fortner *et al*. (2000) showed that people were more likely to "support environmental education in schools" or "installation of low energy light bulbs" and less favored to "use of public transportation" or "support for an increase in gasoline prices" (p. 136). In other words, even if the students were certain about humans' impact on global climate change, it is hard to change their lifestyle, regardless of their scientific knowledge of climate change.

While there is still room for improving the course, we believe that the current study has important implications for other courses or programs for climate change education. First, by presenting historical and archaeological evidence of interaction between climate change and human society, the course not only improved the students' scientific knowledge of climate change but also their critical thinking on evaluating the correlation between climate and human society as well as other human-made factors in the correlation. Second, the course affected the students' information literacy in science by offering opportunities to research, evaluate, and present their ideas about the topic of climate change and human interactions. The course instructor's scientific knowledge and insights about climate change also played an important role to guide students to find the appropriate evidence to support their ideas.

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