International Journal for the Scholarship of Teaching and Learning

Volume 18 | Number 1 Article 11

May 2024

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Abstract

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Keywords

Climate change, Interdisciplinary, Co-teaching, HIPs, CURE, Environment, Anthropology, Ecology

Cover Page Footnote

The authors would like to thank Steven Engel and Francis Desiderio of the Honors College of Georgia Southern University, as well as the dedicated and promising students of these classes for their enthusiastic participation in the class discussions, projects, and research experiences.

Innovative Climate Pedagogy: Interdisciplinary Approaches to Teaching Climate Change

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Received: 10 November 2023; Accepted: 12 February 2024

As a "wicked problem," climate change requires interdisciplinary understanding and collaboration in order to prepare future leaders to develop solutions. To this end, as an ecologist and an anthropologist at a mid-sized university in the southeastern U.S., we designed a pair of interdisciplinary, research-intensive courses for first-year Honors students with the goal of improving understanding and communicating the urgency of climate change. We employed High Impact Practices (HIPs) and Course-Based Undergraduate Research Experiences (CUREs) to accomplish learning outcomes during both years of the course. Gains in scientific knowledge and climate change-specific knowledge were assessed with quantitative and qualitative analysis of pre and post-tests. Analysis suggests that the course improved climate change knowledge and sophistication of interdisciplinary thinking and increased student confidence in understanding of the process of science. This course structure offers an approach to providing a practice space for developing multifaceted solutions to wicked problems.

INTRODUCTION

Wicked Problems

Defined as complex issues with no simple or clear solutions, wicked problems are prevalent in 21st century society (Rittel & Webber, 1973). Different stakeholders approach wicked problems in completely different ways depending on their own opinions or based on incomplete or contradictory knowledge. Proposed solutions may have unintended consequences, and often carry a large economic and ethical burden. Proposed solutions may change over time, as wicked problems are interconnected with other problems in ways that may not be clear at the onset. There is no single template that can solve the problem completely, as it may differ from context to context, and there are no ways to test the potential solutions without real-world consequences.

In 2020, Georgetown Provost Randy Bass suggested the application of the term to higher education itself, arguing: "We need to think of the problem of learning– and by implication, the problem of higher education– as a complex, *wicked* problem… as an invitation to think more broadly and ambitiously about the role of educational development in the reconfiguration of higher education and the role of education in the broader learning ecosystem" (Bass, 2020, p.6). Similarly, Laura Cruz, editor of *Transformative Dialogues: Teaching and Learning Journal,* furthers this argument in 2022, urging scholars to stop looking for simple solutions, but rather to "deepen our insights, strengthen our empathy, and embrace a plurality of voices in ongoing scholarly dialogue about teaching and learning" (Cruz, 2022, p.2).

Teaching Strategies

This problem emerges within the literature on the Scholarship of Teaching and Learning (SOTL), in which various approaches address wicked problems, utilizing multiple techniques. Interdisciplinary approaches to teaching are fairly common (Gerhard & Mayer-Smith, 2008; White & Nitkin, 2014; Johansen et al., 2009), incorporating disciplines such as graphic design, marketing, nursing, and public health. These settings allow students to explore a variety of disciplinary perspectives on a single topic to learn that often approaches to problem-solving are myriad and diverse.

Co-teaching is an alternate approach, sometimes incorporating interdisciplinarity through the inclusion of more than one educator for a class (Rooks et al., 2022) or incorporating a mentorship model (Cordie et al., 2020; Devlin-Scerer & Sardone, 2013). Students in co-taught courses are able to witness professional collaborations, and have effective communication between scholars demonstrated for them on a regular basis.

High Impact Practices (HIPs) emerged in 2008 as Kuh et al identified ten promising features that would facilitate learning for students. This list of ten (now eleven) HIPs includes practices that take place both inside and outside of the classroom. Several of the approaches naturally fit together and can coexist in the same course or set of courses, such as First Year Seminars to bring new students together with faculty on a regular basis, and Learning Communities in which a group of students is enrolled together in two or more linked courses focusing on a common theme. Similarly, approaches like Collaborative Assignments and Projects that incorporate team-based assignments, cooperative projects, and research, and Undergraduate Research to connect key concepts with student's early and active involvement in systematic investigation, can be easily addressed by a single class or set of assignments (Sweat et al., 2013; Swaner & Brownell, 2008). Other HIPs, such as independent Internships or cumulative ePortfolios, are only possible outside of the individual classroom.

A different approach to undergraduate education is captured in Course-Based Undergraduate Research Experiences (CUREs). CUREs have been shown to provide many of the same benefits as traditional undergraduate research experiences, including gains in content knowledge and technical skills, improved understanding of the nature of science, increased confidence, greater project ownership, and openness to new career paths, and are thought to be particularly beneficial for underrepresented groups (Auchincloss et al., 2014; Corwin et al., 2015; Genet 2021; Hanauer et al., 2017; Krim et al. 2019; Lapatto, 2007; Russell et al. 2015). In a CURE, undergraduate research is a component of the classroom experience, which makes it less resource-intensive for universities and more accessible to students (DeChenne-Peters et al,. 2022). Given these many benefits, CUREs have the potential to be of

https://doi.org/10.20429/ijsotl.2024.180111

particular use in helping students to understand wicked problems from multiple perspectives.

Climate Change Education

An example of a wicked problem that confronts the current generation of students is climate change. Kelly, McCright, and Deitz (2015) argue that knowledge of the science around climate change is weak among college students (Sterman & Sweeney, 2007; Hartley et al., 2011) partly because it is a difficult topic for instructors to teach in a way that effectively supports student learning (Kirk et al., 2014). While multiple disciplines, such as political science or philosophy, could be useful in addressing these problems, these authors point to the need for social sciences to engage with climate change education in order to teach "insights on the social drivers, dynamics, and impacts of climate change" (Kelly et al., 2015, p. 49), but note that it is unreasonable to expect social scientists to effectively teach both social science and the biological and physical science content to effectively educate students on climate change. While these scholars solve this dilemma through the use of existing online science modules to convey the climate change science content, the authors of this paper instead utilized an interdisciplinary, co-teaching model to bridge the gap between the natural and social sciences, via the mechanism of two consecutive, co-taught freshmen honors seminars on climate change.

The incorporation of different pedagogical models into interdisciplinarily addressing a wicked problem could be a disjointed process were it not for the guiding principle of the critical pedagogy of sustainability (Evans, 2012). This principle argues that ecological crises such as impending climate change require intensive discourse and "participatory pedagogy" where students are given the opportunity to integrate new knowledge and the support to wrestle with cognitive dissonance. Evans (2012) argues that higher education is a space in which environmental crises can be addressed and student agency can be enacted through informed participation in local action.

Case Study

Faced with the task of educating students to tackle the challenges of the 21st century, and in an effort to bridge disciplines, the Honors College at a mid-sized, southeastern university invited the authors, a coastal dune ecologist and an applied cultural anthropologist, to select a wicked problem to be addressed by our respective scientific fields. We implemented an interdisciplinary approach to understanding and communicating the urgency of climate change, and collaboratively created and taught two semesters of a pair of interdisciplinary, research-intensive courses to introduce first-year students to the science behind the problem. These co-taught classes enacted the guiding principle of critical pedagogy of sustainability (Evans, 2012) through the incorporation of science based, active engagement with practical applications of student learning that had the potential to result in real action in their own communities.

The courses both focused on critical thinking skills, learning the natural science behind the problem of climate change and the impacts of climate change on human lives and cultures, a deliberate and repetitive integration of the respective disciplines, and the core guiding objective of engaging students in research and constructive, real-world application of their findings. Concurring with the belief that sustainability-related change in behavior and beliefs can–and often does–start in the classroom (Grauerholz et al., 2015; Savageau, 2013) we ensured that this collaboration provided the materials necessary to spark this change.

Here we present a case study of the courses and evaluate their success using a mixed methods approach, comparing pre- and post-tests to determine students' 1) perceived understanding of the nature of science/ the scientific process, 2) perception of the severity of climate change effects, and 3) knowledge of the causes and consequences of climate change. We also compared students' scientific literacy before and after the course with that of the general American public.

METHODS

Participants

Freshman Honors students at this university were enrolled in two three-credit Honors Inquiry courses: Honors Inquiry in the Social Sciences and Honors Inquiry in the Natural Sciences, which were taught back-to-back for 75 minutes each, twice a week. The courses were offered in two consecutive years: Fall 2021 (13 students) and Fall 2022 (12 students). Students were of traditional college age and the majority were from the southeastern United States.

Course Design and Projects

Over the course of 16 weeks, students met twice a week for two hours and 30 minutes in each session, with one eight-hour field trip on a Saturday. Instructors focused on the following learning outcomes:

Natural Science Learning Outcomes

1. Identify the causes and consequences of climate change, and evaluate climate change solutions from the perspective of natural science
2. Articulate different ways of understanding climate change across the natural sciences
3. Ask and answer a research question focused on climate change
4. Identify the benefit of natural science approaches to developing climate change solutions

Social Science Learning Outcomes

1. Understand the scope and value of social sciences broadly, anthropology in particular
2. Learn & practice basic social science research methods relevant to our wicked problem
3. Understand how social science concepts and methods are crucial to addressing urgent real-world problems like climate change

Four integrative course projects were assigned to accomplish these learning outcomes, including

1. *CRAAP Test*: reading of a critical thinking textbook followed by the independent evaluation of two student-selected articles with the CRAAP test (for Currency, Relevance, Authority, Accuracy and Purpose)
2. *Infographic:* a team project integrating natural and social science knowledge about climate change causes and consequences to communicate climate change to the general public.
3. *Field Research and Report*: a collaborative climate change field study employing natural and social science methods to evaluate the effectiveness of a coastal resilience adaptation strategy on Tybee Island, Georgia.

4. *Grant Proposal:* collaborative development of a sustainability grant proposal to develop a climate change solution to be implemented on the university campus.

Each project addressed two to six SLOS (Table 1) and employed two to seven HIPs (incorporating those that are able to be addressed in the classroom, as some are structurally impossible to fit into a class experience), and the Field Research was designed as a CURE and a service-learning project (Table 2).

Table 1. Relationships between Natural Science (NS) and Social Science (SS) course Student Learning Outcomes (SLOs) and Integrative Course Projects.

Project	**NS SLO 1**	**NS SLO 2**	**NS SLO 3**	**NS SLO 4**	**SS SLO 1**	**SS SLO 2**	**SS SLO 3**
CRAAP Test		x				x	
Infographic	x	x		x	x	x	x
Field Research & Report	x	x	x	x		x	x
Grant Proposal	x	x		x	x	x	x

ASSESSMENT: SCIENTIFIC LITERACY, CLIMATE KNOWLEDGE AND ATTITUDES TOWARDS SCIENCE

In order to situate the classroom learning of these courses into a larger conversation about scientific education and understanding, the authors incorporated existing research instruments from both local and national sources. Questions concerning causes and consequences of climate change that had been used previously in one of the author's Environmental Biology courses were included to assess student knowledge of the science behind climate change. Other questions drew on the National Science and Engineering Indicators, which are a measure of the American public's attitudes, knowledge, and interest in science and technology (See Appendix; National Science Board, 2020). Human subjects research approval for this project was granted by the university's Institutional Review Board.

Each year the National Science Board and the National Science Foundation develop and administer surveys to assess the current environment of understanding and perceptions in the country, in order to provide high-quality quantitative information that is intended to inform the President, Congress, and future policies (National Science Board, 2020). Various iterations of this survey have been conducted since the 1970s, with nine constant, core questions on scientific statements that are not expected to change over time (e.g. "Does the earth go around the sun or the sun around the earth?"). Drawing questions from this survey, the overall impact of the class was assessed via pre- and post-semester deployment of some of these scientific literacy questions.

Scientific Literacy data, including knowledge and perception questions, were gathered via a confidential online survey in Qualtrics that consisted of twenty-seven multiple choice questions and two open-ended questions (Table 3). Perception/attitude questions employed Likert scale responses from strong disagreement to strong agreement. These surveys were administered in the classroom on the first day of the fall semester in both 2021 and 2022, referred to as "pre-class surveys" and on the last day of class each year, referred to as "post-class surveys." Each student was asked to enter a pseudonym to be used to link the pre- and post-class survey responses. They were instructed: "Please select a common first and last name DIFFERENT FROM YOUR OWN that you will (1) not share with your instructors or classmates, and (2) remember for the post-semester assessment in December. Write this pseudonym in the space below." For the post-class survey, they were asked to recall that original pseudonym, and in both years, the instructors read the list of pseudonym names aloud to remind the students of those names. Testing occurred during the class period on students' personal devices, and adequate time was provided to allow for full responses.

ASSESSMENT: ANALYSIS

Quantitative Data Analysis

Student responses for the ten general scientific knowledge questions (questions 4-13, Appendix) were coded as 1 for correct and 0 for incorrect. We calculated a composite scientific literacy score for each person by summing responses to all ten questions (0-10 points). Student responses to four climate change knowledge questions (questions 14, 23-25, Appendix) were coded similarly, except for question 24 (Humans have altered the carbon cycle by…) which was coded as 0 for incorrect, 1 for one correct answer (B or D) and 2 for the fully correct answer (B and D). Composite climate scores ranging from 0-5 points were calculated for each student. Composite scientific literacy and climate scores were each compared from pre- to post-tests with paired t-tests within each year.

Individual Likert scale perception questions concerning the student confidence in understanding the process of science, char-

Table 2. Alignment of required course projects with 11 High Impact Practices (HIPs) and CURE.

Assignment	**C**	**H1**	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**	**H8**	**H9**	**H10**	**H11**
CRAAP Test		x			x							
Infographic		x				x		x				
Field Research	x	x			x	x	x	x		x		
Grant Proposal		x			x	x				x		
Across the Entire Course		x	x	x	x	x	x	x				

Column C indicates the CURE.
HIPs include: H1 First-Year Seminars and Experiences, H2 Common Intellectual Experiences, H3 Learning Communities, H4 Writing-Intensive Courses, H5 Collaborative Assignments and Projects, H6 Undergraduate Research, H7 Diversity/Global Learning, H8 ePortfolios, H9 Service Learning, Community-Based Learning, H10 Internships, H11 Capstone Courses and Projects.

Table 3. Comparison of performance on scientific literacy questions by Honors Inquiry students at the start of the semester in 2021 and 2022 and by most recent Science and Engineering Indicators survey for the United States (National Science Board, NSF 2020).			
Survey Question	**Honors Inquiry Pre-test**		**S&E Indicators**
	2021 (*n*=12)	**2022 (*n*=11)**	**U.S. 2018 (*n* = 1,175)**
The center of the Earth is very hot. (True)	100.0	100.0	86
The continents on which we live have been moving their locations for millions of years and will continue to move in the future. (True)	91.7	90.9	79
Does the Earth go around the Sun, or does the Sun go around the Earth? (Earth around Sun)	91.7	90.9	72
All radioactivity is man-made. (False)	91.7	100.0	68
Electrons are smaller than atoms. (True)	83.3	45.5	46
Lasers work by focusing sound waves. (False)	58.3	63.6	44
The universe began with a huge explosion. (True)	58.3	90.9	38
It is the father's gene that decides whether the baby is a boy or a girl. (True)	75.0	81.8	59
Antibiotics kill viruses as well as bacteria. (False)	50.0	63.6	50
Human beings, as we know them today, developed from earlier species of animals. (True)	58.3	100.0	49
Note: Scores are percentage of respondents answering correctly.			

acteristics and motives of scientists, and the severity of the effects of climate change were also compared from pre- to post-tests with paired t-tests within each year. All quantitative analyses were conducted with JMP Pro 16.0 (SAS 2021).

Qualitative Data Analysis

In order to elicit student perspectives and concerns, this survey incorporated limited qualitative data, consisting of student responses to two questions: "What do you consider to be the greatest environmental problem of (this year) and why?" and "What do you consider to be the greatest environmentally-related social problem of (this year) and why?" Students typed their responses directly into a Qualtrics survey. This qualitative data was analyzed using open, inductive coding. We carefully read and re-read these notes and transcripts, looking for common themes and patterns to emerge in the participants' responses to these two questions, both prior to and after completing the course. When these recurring ideas emerged, we identified salient analytic categories (Emerson et al., 2011). Those categories were then quantified to identify the most common themes, and the responses examined for phrasing, complexity of thought, presence of multiple themes in a single response, and the ability to identify connections both within and across the natural and social science perspective. These data are discussed in the Results below.

RESULTS

As planned, we delivered content via the four projects, in a similar fashion across both years of the course. Students performed well, earning As and Bs on the final products from each task, demonstrating improved interdisciplinary understanding of the wicked problem of climate change as the course progressed each year. Twenty-five students completed the pre-test surveys, 13 in 2021 and 12 in 2022. One student dropped the course in 2021 and in 2022 one student did not complete the post-survey. As a result, the post-test survey sample size was reduced to 12 and 11 students respectively.

Scientific Literacy Results

Quantitative data

Classes in both years scored 17 to 23.5% higher than the general US population in scientific knowledge as based on Science and Engineering indicators (76% and 82% correct responses respectively compared to 59% for the general U.S. public; Table 3). However, general scientific knowledge did not increase from pre- to post-test for our students in either year (Table 4). Composite scores of specific climate change knowledge averaged 72.8% to start, and improved to 85.4% in 2022, but did not improve significantly in 2021, though student understanding of why the burning of fossil fuels causes climate change (#23) improved by 41.5% in 2021 and 27% in 2022 (Table 4).

Student perceptions of scientists and their motives were similar to those of the general US population in both years (Table 5); most agreeing that scientists work for the good of humanity, help to solve problems and want to make life better for the average person. Student perception of their personal understanding of the concept of a scientific study improved by about 15% in both years, yet no measure of perception of scientists or their motives, or importance of federal funding for science changed significantly in either year. Student perception of the severity of the effects of increasing temperature due to climate change increased by 13% in 2021 and trended toward an increase of 11% in 2022 (P=0.056; Table 4).

Qualitative Evidence for Scientific Literacy

The responses offered by the students of 2021 did not differ dramatically from the responses given in 2022, so the replies have been combined for qualitative analysis into two data sets: pre-class and post-class. After completing coding and identifying themes, themes were quantified to determine frequency of response. All responses volunteered by at least three students are identified and discussed in these results.

Pre-Class Responses

Prior to the course, students demonstrated a variety of concerns about different environmental issues (Table 6). In response to the question about the current greatest environmental problem, they gave answers citing global warming (N=7), plastic waste (N=4), and carbon emissions (N=4) most commonly. The presentation of these concerns varied, ranging from explanations that linked animal food production to an increase in deforestation, to those that demonstrated a less concrete understanding of the linkages, such as the student who responded "To be honest, I don't know much about environmental problems, but I do now that the world is heating up and it sucks."

Table 4. Matched pair analysis results for difference in response between pre- and post-test for University Honors Inquiry students in 2021 and 2022.

Survey Question	Mean Difference	*SE*	*t*-ratio	*df*	*P* (one tailed)
#15 HONS 2021	0.417	0.193	2.15	11	**0.027**
#15 HONS 2022	0.455	0.157	2.89	10	**0.008**
#16 HONS 2021	0.556	0.242	2.29	8	**0.026**
#16 HONS 2022	0.2	0.2	1	9	NS
#17 HONS 2021	0.667	0.333	2	11	**0.035**
#17 HONS 2022	0.545	0.312	1.75	10	0.056
#18 HONS 2021	0.333	0.31	1.08	11	NS
#18 HONS 2022	-0.091	0.368	-0.25	10	NS
#19 HONS 2021	0	0.213	0	11	NS
#19 HONS 2022	0.364	0.243	1.49	10	0.083
#20 HONS 2021	-0.167	0.345	-0.48	11	NS
#20 HONS 2022	0.273	0.195	1.4	10	0.096
#21 HONS 2021	0.167	0.241	0.692	11	NS
#21 HONS 2022	0.182	0.263	0.69	10	NS
#22 HONS 2021	-0.333	0.333	-1	11	NS
#22 HONS 2022	0.273	0.304	0.9	10	NS
Composite Sci Lit 2021	0	0.348	0	11	NS
Composite Sci Lit 2022	-0.091	0.563	-0.16	10	NS
Composite Climate 2021	0.5	0.435	1.15	11	NS
Composite Climate 2022	0.636	0.31	2.06	10	**0.034**

Several types of questions are included: self-reporting of understanding of scientific process (#15), individual perception of severity of climate change (#16-17) perception of scientists (#19-22), composite science literacy scores, and composite climate knowledge scores. Test statistic (*t*-ratio), degrees of freedom (*df*), mean response difference and standard error of difference listed. Significant differences between pre- and post-tests are indicated in bold, and all *P* values <0.10 are included..

Table 5. Perception of scientists by Honors Inquiry students at the start of the semester in 2021 and 2022 and most recent Science and Engineering Indicators survey for the United States (National Science Board, NSF 2020).

Survey Question and Likert Responses	Honors Inquiry Pre-test data		S&E Indicators
	2021 (*n*=12)	2022 (*n*=11)	U.S. (2018, *n* = 1,175)
#19 Scientists work for the good of humanity			
Strongly agree	33.3	27.3	26
Agree	66.7	63.6	63
Disagree	0	0.09	7
Strongly disagree	0	0	1
Don't know	0	0	2
#20 Scientists help to solve problems			
Strongly agree	58.3	36.4	27
Agree	41.7	63.6	66
Disagree	0	0	5
Strongly disagree	0	0	*
Don't know	0	0	1
#21 Scientists want to make life better for the average person			
Strongly agree	25	36.4	22
Agree	75	63.6	67
Disagree	0	0	8
Strongly disagree	0	0	1
Don't know	0	0	2
#22 Scientists are odd and peculiar			
Strongly agree	25	9.1	10
Agree	50	36.3	40
Disagree	25	45.5	39
Strongly disagree	0	9.1	7
Don't know	0	0	4

Note: Numbers indicate percent of participants selecting that response.

Table 6. Student responses to question: What do you consider to be the greatest environmental problem [of this time], and why?

Pre-Class Response	Post-Class Response
It would be global warming but to be more specific, an extremely pressing issue to me would be the wildfires on the West coast.	The biggest environmental problem is the burning of fossil fuels. This is increasing the CO2 levels in the world which keeps the climate warming.
Uh, I am very under educated in the field. So, in my ignorance I am going to say the issue of plastic waste or CO2 emissions?	Sea level rise as it will cause people to move and land to go under water. Mass production of CO2 as it is causing the oceans to become more acidic and creating a thicker greenhouse effect which causes increase temperatures.
Global warming	I consider the greatest environmental problem to be the burning of fossil fuels because we use fossil fuels for a lot of our energy, and they are nonrenewable as well as release a lot of the carbon that is currently in our atmosphere.
Carbon emissions	I think the greatest environmental problem is deforestation, which released CO2 into the atmosphere while simultaneously reducing the sinks available to absorb the CO2 in the atmosphere
I believe that the increase of global warming (although it died down during Covid-19) it is a rising concern in the environment that I believe needs to be solved.	Release of CO2 in our atmosphere and pollution of our water and the burning of fossil fuels rising the temperature in all.
Monopoly companies who overproduce and poor working conditions that lead to severe health problems as well as emit toxic chemicals into our environment.	The greatest environmental problem is overconsumption. In all aspects, people overproduce and we are living well above the Earth's means. Too much electricity is being used and spaces are not being reworked to save energy. Overconsumption also affects the trees seeing as we have a severe deforestation and food insecurity problem because we are producing more than we can actually utilize.
To be honest, I don't know much about environmental problems, but I do know that the world is heating up and it sucks	Even though there are many problems, I think the greatest one is the temperature rising, because as the temperature rises people have to spend more money on their AC, which increases energy costs and to be honest when it's really hot going outside isn't fun like it should be.

Other student responses touched on a wide variety of issues, ranging from melting ice (*N*=3) to water pollution (*N*=3), to litter/trash in their local environment (*N*=3). One student explained "The greatest environmental problem of 2021 would be pollution. People just throw their trash where they want and it makes the world look dirtier than what it should be."

The 25 students who took the survey offered a total of 49 topics in response to the question, meaning that each student mentioned a mean average of two concerns, yet nearly half of the students only offered a single concern.

During this same pre-class survey, students were asked to cite what they felt was the "greatest environmentally-related social problem" of the time, and responses to this question were limited and often vague (Table 7). The most common response addressed human understanding of or reaction to the idea of climate change (*N*=6), but the same number of respondents (*N*=6) either left the question blank or said they didn't have an answer (such as the student who commented "No idea, to be honest."). Answers argued that "climate change is in politics. People are arguing if it does or doesn't exist instead of fixing the problems at hand," while another student asserted "Not many people actually believe in climate change."

A small section of the class mentioned air pollution in response (*N*=3), with one student explaining that "Pollution in India causes lung problems for people and a fog over the large populated cities." However, the remainder of the responses were only mentioned by 1 or 2 students, and covered "pushback against renewables and electric items, specifically cars," "the exploitation of animals" and COVID-19.

Post-Class Responses

Survey replies demonstrated dramatic differences between the pre- and post-test data (Tables 6 and 7). In response to the question about the current greatest environmental problem, the majority of the class answered carbon emissions (*N*=9) and/or global warming (*N*=8). Fossil fuels (*N*=4) and water and air pollution (*N*=3) were also common answers. In many cases, the responses identified several interrelated environmental problems, such as "The biggest environmental problem is the burning of fossil fuels. This is increasing the CO2 levels in the world which keeps the climate warming" or this thorough explanation:

> *I think the greatest environmental problem of 2021 is pollution. The amount of plastic in landfills and in the ocean is detrimental for the environment. Plastics in landfills do not biodegrade and cause an increase in GHG in the atmosphere. Plastic in the ocean suffocates it and ruins the habitats of many ocean animals. Overall, with the increase in GHG, the temperature rises and the ocean uptakes CO2, causing animals to suffer. We need to get a handle on pollution because it will end up causing bigger problems that people aren't thinking about right now.*

Similarly, the responses to the second question about environmentally-related social problems were also more complete and confident. The most common answer centered on human responses to climate change, saying "Not enough people are talking about climate change or other problems. I think that it should be discussed more so that people can discuss ways to reverse climate change." Another identified the biggest problems as the "divide in opinion on climate change, which has irrefutable facts and evidence that it is indeed happening." Students also identified a disconnect between environmental issues, average people, and political implications (*N*=7). They explained that "People just can't seem to fully agree with if [climate change] is real or not but the fact is it is very real and happening now. They focus more on the political argument than the issue itself," and "...there isn't enough information going out to the public about how serious climate change is and how it has become a political issue when it should just be considered a people issue."

The final two common categories addressed people's lack of education about climate issues (*N*=5) as well as inequality (*N*=5). They asserted that "The greatest social problem related to the environment is ignorance. I feel that there isn't enough information going out to the public about how serious climate change is" and "I think the greatest environmentally related social problem is the disproportionate effects on lower class people during any sort of natural change." Several, like this student, identified the connections between the issues:

> *...education is still the biggest environmental problem in 2021. People know too little about climate change and it has made it a political issue that is not seeing progress. We also cannot further benefit society and make changes and progressions to helping poor marginalized groups because we do not take the effort to notice the effects to these communities.*

The final component of qualitative analysis focused on the individual shifts in each student's knowledge from the beginning to the end of the semester. In comparing both pre- and post-class responses given by each student, it became clear that each student advanced in their analytical thinking, although the ultimate level of their final understanding might vary dramatically between the different students. Most demonstrated increased complexity in their explanations, often indicating understanding of multiple causes. For example, a student whose pre-test answer was "global warming" responded to the post-test identifying the human tendency to burn fossil fuels for energy, mentions that they are non-renewable resources, and that their use is releasing carbon into the atmosphere. This description illustrates more sophisticated thinking about the connections between human choices and environmental impacts at the conclusion of the course. Examples of these individual shifts in understanding are included in Tables 6 and 7.

DISCUSSION

The learning outcomes for each of the disciplines were explicitly addressed via the four course projects (Table 1). Those projects combined both disciplines in a concrete manner that allowed students to experience and practice interdisciplinary thinking. Based on the tenants of HIPs and CUREs, they explored new ways of knowing, and integrated a spirit of inquiry that engaged them in not only learning of the natural and social science of climate change, but then tasked them with identifying and creating solutions to these challenges (Table 2). The students were able to demonstrate their command of this new, interdisciplinary set of perspectives through their successful completion of these assignments throughout the course, but also via the post-semester survey. We found overall that while the course was not effective in improving general scientific knowledge, it did improve climate change knowledge and sophistication of interdisciplinary thinking.

General Scientific Knowledge

Not surprisingly, honors students scored higher than average Americans in baseline scientific knowledge. This measure simply

Table 7. Student response to question: What do you consider to be the greatest environmentally related social problem [of this time], and why?

Pre-Class Response	Post-Class Response
Too much concern with making money than about keeping the planet alive and thriving for future generations	I think the greatest environmentally related social problem of 2021 might be the lack of responsibility in individuals to work towards behaviors and actions that help go against the effects of climate change because they don't know what to do, don't believe they can do much to affect it, or don't believe climate change is happening to begin with.
There needs to be more concern about global warming	The greatest social problem related to the environment is ignorance. I feel that there isn't enough information going out to the public about how serious climate change is and how it has become a political issue when it should just be considered a people issue.
The loss of homes due to flooding and competition over natural resources because people are becoming refugees because they are forced to leave their homes because of something out of their control.	I think the greatest environmentally related social problem of 2021 is sea level rise. With the increase in temperature melting the ice caps, it is causing places to flood and displace people. It takes away the security of having somewhere to live. As sea level continues to rise, more cities will flood and more people will have nowhere to go as a result.
The pushback against renewables and electric items, specifically cars. While electric cars wouldn't have anywhere near zero emissions, they'd have way less than a gas/fossil fuel powered car. The social campaigns claiming some "purity" of gasoline and the "American Way" hinder efforts to move forward in this area.	Media with the intent of discrediting peer-reviewed research for political agendas, because this is a huge barrier to actual, institutional change.
I think environmental degradation is a problem that can be accelerated by humans. It involves the natural climate being compromised by some way. It reduces the health of the environment.	Each environmental problem can be related back to social problems because they challenge us to change certain patterns or behaviors. Waste could also be one of the greatest problems of 2021. If the food does not look pretty enough or is aesthetically pleasing it will be thrown out adding to the social issue of food waste.

anchored our honors student population in the context of the broader U.S. population and suggests that they were moderately knowledgeable about basic scientific principles. That their composite scientific knowledge scores did not significantly improve over the course of the semester is not surprising, given that the course focus was climate change and that none of the other basic scientific knowledge questions were explicitly addressed.

As measured herein, this course also did not change students' perception of scientists, their motives or the value of federal funding of science. While we would have liked to see improvement in attitudes towards science, this was not our goal or a stated learning outcome. As a result of the enrollment criteria for the course, very few of the students were natural science majors, and may have been less likely to hold the most positive perceptions of scientists.

In both years, the course resulted in a significant improvement in student confidence in understanding the scientific process. This finding is supported by other studies on the outcome of CUREs (Auchincloss et al., 2014; Corwin et al., 2015; Genet, 2021; Hanauer et al., 2017; Krim et al., 2019; Lapatto, 2007; Russell et al., 2015).

Knowledge and perception of climate change

Quantitative change in composite knowledge of climate change was mixed depending on the year. Classes were small and this made it more difficult to detect a difference between pre- and post-test scores, particularly with only 11 students in the sample in 2022. But students' knowledge of the causes of climate change in terms of increased sources (CO_2 emissions from fossil fuels) and decreased sinks (deforestation and loss of carbon fixation) was significantly improved.

Post-class qualitative responses indicated a tendency to describe the interconnectedness of multiple issues. Many student responses offered increased explanation of specific mechanisms of climate change and carbon emissions—in contrast to the pre-class answers in which many simply named a phrase or topic.

This improved understanding was evident in the questions about social problems as well. Regardless of quantitative scores on knowledge questions, students showed a clear improvement in sophistication of knowledge about climate change not just in terms of its natural science causes but its impacts on global society. The post-class qualitative responses demonstrated a more multifaceted understanding of cause and effect; not just within the natural sciences, but also the subsequent impacts on human lives around the globe. The students showed a deeper comprehension of the interrelatedness of the natural processes, and the inescapable human embeddedness in the natural environmental systems of the planet. The shift in perception of the severity of time impacts of climate change also illustrates students' improved ability to relate environmental cause and effect to global societies.

CONCLUSIONS

As educators, we found the impacts of the course to be multifaceted. While the survey results indicate an advancement in student thinking, they do not fully capture the outcomes of these courses. The courses provided a space in which students were educated about the scientific process, and the science of climate change and the impact it has– and will continue to have– on their lives. By guiding students through activities that allowed them to interact with small-scale solutions to those issues at both the natural and social science levels, we were able to instill confidence and a long-range, broad-scale perspective to accompany students as they left the class. This approach could be equally fruitful in different interdisciplinary combinations across the arts and humanities, engineering, business, public health and more.

As a result of completing these tasks in the classroom, students were empowered to transfer these knowledge and skill sets outside the classroom to address real world problems with an interdisciplinary toolkit. While wicked problems are characterized by our inability to test potential solutions for them without real-world consequences, this type of practice space allows students to begin to ponder how to transfer this knowledge outside of the university setting. Wicked problems require creative, new approaches, and the success of this course indicates that perhaps productive solutions can be created in this interdisciplinary space.

On a broader scale, student engagement with these courses also demonstrated learning that is more difficult to measure. As instructors, we were not simply concerned with improved knowledge. We hoped to integrate understandings of the wicked problem of climate change across both disciplines in order to allow students to perceive problems and solutions from multiple perspectives. An unintended side benefit of this co-teaching format was that students were able to witness lifelong learning and collaboration firsthand. They were part of classroom exchanges as we interacted with each other– asking questions to clarify our understanding of each other's disciplines or to think critically about how to apply new pieces of knowledge. They could witness our high levels of mutual respect even as we challenged each other with new ways of thinking. We modeled excitement and respect for the interdisciplinary approach, in particular as we explored solutions to wicked problems.

Leaders in higher education, such as Georgetown Provost Randy Bass (2020), point to the current and future "wicked problem" of how best to educate students of today and tomorrow. Simultaneously this same generation is facing global issues unlike any we have encountered in recent decades, with the "wicked problem" of climate change impacting world populations at unprecedented levels. In response to these simultaneous issues, we present this case study model as a potential remedy. Through in-class incorporation of skill building, integration of critical thinking skills and practical opportunities for problem identification and problem solving, our students were able to witness firsthand that solving the wicked problems that face their generation will likely require interdisciplinary approaches. They will need to be lifelong learners to be effective problem solvers.

ACKNOWLEDGEMENTS

The authors would like to thank Steven Engel and Francis Desiderio of the Honors College of Georgia Southern University, as well as the dedicated and promising students of these classes for their enthusiastic participation in the class discussions, projects, and research experiences.

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APPENDIX

Scientific Literacy Survey given to students at the beginning and end of each course via Qualtrics. Questions 4-22 and 26-44 drawn from National Science Board 2020.

1. Sex
   a. Male (1)
   b. Female (2)
   c. Intersex / Non-binary / third gender (3)
   d. Not listed: (4) ____________________
   e. Prefer not to reply (5)

2. Age ______

3. Please select a common first and last name DIFFERENT FROM YOUR OWN that you will (1) not share with your instructors or classmates, and (2) remember for the post-semester assessment in December. Write this pseudonym in the space below.
   ____

<u>Answer Options for the following questions are "True" or "False"</u>

4. The center of the Earth is very hot.
5. The continents on which we live have been moving their locations for millions of years and will continue to move in the future.
6. The Sun goes around the Earth
7. All radioactivity is man-made.
8. Electrons are smaller than atoms.
9. Lasers work by focusing sound waves.
10. The universe began with a huge explosion.
11. It is the father's gene that decides whether the baby is a boy or a girl.
12. Antibiotics kill viruses as well as bacteria.
13. Human beings, as we know them today, developed from earlier species of animals.
14. The greenhouse effect did not exist before humans.

15. When you read or hear the term scientific study, do you have a:
    a. clear understanding of what it means
    b. a general sense of what it means
    c. little understanding of what it means

<u>Answer Options for the following questions are (1) Extremely dangerous, (2) Very dangerous, (3) Somewhat dangerous, (4) Not very dangerous, (5) Don't know</u>

16. In general, do you think that a rise in the world's temperature caused by the "greenhouse effect" is ___
17. In general, do you think that a rise in the world's temperature caused by climate change is___

<u>Answer Options for the following questions are: (1) Strongly agree, (2) Agree, (3) Disagree, (4) Strongly disagree</u>

18. Even if it brings no immediate benefits, scientific research that advances the frontiers of knowledge is necessary and should be supported by the federal government.
19. Scientific researchers are dedicated people who work for the good of humanity.
20. Scientists are helping to solve challenging problems.
21. Most scientists want to work on things that will make life better for the average person.
22. Scientists are apt to be odd and peculiar people.

23. Why does burning fossil fuels cause climate change?
    a. Burning fossil fuels destroys the ozone layer.
    b. Organic matter trapped in coal, oil, and natural gas becomes carbon dioxide when these fuels burn.
    c. Burning fossil fuels removes water vapor from the atmosphere.

24. Humans have altered the carbon cycle, by
    a. increasing photosynthesis
    b. reducing the uptake of CO2 from the atmosphere
    c. increasing evaporation
    d. increasing the release of CO2 in the atmosphere
    e. B and D

25. Which of the following are consequences of present-day global warming that have already taken place?
    a. Average sea level rose by 8-9 inches since 1880
    b. Droughts increased in frequency and severity
    c. 2011-2020 was the warmest decade in recorded history
    d. Birds, plants and insects moved their ranges toward the poles or upward in elevation where it is cooler
    e. All of the above

<u>We are faced with many problems in this country, none of which can be solved easily or inexpensively. The table below names some of these problems, and for each one, please indicate if you think we're spending (1) too little money on it (2) about the right amount, or (3) too much money</u>

26. Education/ Improving the nation's education system
27. Assistance for the poor
28. Environment / Improving and protecting the environment
29. Drug rehabilitation / Dealing with drug addiction
30. Law enforcement / Halting the rising crime rate
31. Social security
32. Assistance for childcare
33. Developing alternative energy sources
34. Highways and bridges
35. Assistance to blacks / Improving the conditions of blacks
36. Supporting scientific research
37. Assistance to big cities / Solving the problems of the big cities
38. Mass transportation
39. Parks and recreation
40. National defense / Military, armaments, and defense
41. Welfare
42. Space exploration / Space exploration program
43. Assistance to other countries / Foreign aid

44. If you wanted to learn about scientific issues such as global warming or biotechnology, where would you get information?
    a. Internet
    b. Television
    c. Book or other print
    d. Newspaper
    e. Magazine
    f. Family
    g. Government agency
    h. Friend or colleague
    i. Radio
    j. Library

45. What do you consider to be the greatest environmental problem of [this year] and why?

46. What do you consider to be the greatest environmentally related social problem of [this year], and why?

https://doi.org/10.20429/ijsotl.2024.180111