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A Sustainability and Alternative Energy Course as a Bridge between Disciplines

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Abstract

Knowledge of sustainability, climate change, and environmental impact is far more important now than when engineering curricula were first created and refined in the early 20th century. Making room for these essential topics is an important part of how engineering as a course of study and as a profession navigates our current global pollution epidemic. This paper is on the assessment of a new interdisciplinary course on sustainability and alternative energy offered to Art, Architecture, and Engineering students at The Cooper Union, a small, primarily undergraduate institution. The course provides students with an introduction to sustainability and sustainable development, the basics of energy conversion and storage technologies, and life cycle assessment. As the problems of sustainable development are interdisciplinary, our goal was to attract a multidisciplinary group of students to inspire discussion and different ways of thinking around the political, cultural, and technical components of a near-zero carbon energy future. We demonstrate that students not only learned the material, but also gained a greater appreciation for the climate crisis and how to engineer for sustainability. Course content and structure was aimed to be as interactive as possible, including extensive in-class discussion activities as well as two large group projects where students presented their findings to the class. We intentionally incorporated content and student activities on social equity, environmental justice, and the unequal impacts of a changing climate. Assessment was via student course evaluations, where they reflected on the delivery methods of the course and what they learned. Student survey responses were overwhelmingly positive – students enjoyed the diverse cohort and set of topics, the focus on group work and active discussion via Zoom, and the projects (on a specific renewable electricity generation site and a life cycle assessment). Survey results show that Engineering students were initially more interested in course topics related to technology whereas Art/Architecture students were more interested in course topics related to cultural and political issues; however, after the course, student interest in these topics converged and there was no discernable difference in interest levels across course topics between the two cohorts. We show that students gained an increased appreciation for (and understanding of) both the science/technology and ethical trade-offs in energy system choices. Our assessments (via remote oral presentations, online quizzes, electronic homework, and recorded videos) found that students, regardless of discipline, met course learning objectives despite the limitations of a remote format.

Introduction

According to the United Nations [1], "climate change is the defining issue of our time" – almost every facet of our lives will be affected by either our changing climate or our attempts to adapt to these changes. The impacts will be disproportionately felt by the most vulnerable populations in the world [2], who not only had little responsibility for historical emissions but who have the fewest resources to adapt. To address these ethical, social, cultural, and technical challenges, students today need to understand what they are and why they are happening; previous iterations of engineering curricula were written before the concepts of sustainability and pollution prevention were important topics, creating a gap in higher education which must be filled.

Conventional engineering approaches which separate the economic and ecological consequences of modern technology are outdated [3]. Other authors such as Anholon et al. [4] emphasize the importance of understanding sustainability for engineering students in a crisis context (such as the COVID-19 pandemic) and challenges them to value all aspects of sustainability, not just the economic ones. Sustainable development and environmental education differ, and sustainable development education requires "a complex interdisciplinary approach beyond that found in some areas of traditional environmental education." [5].

Professional societies including ABET stress that global perspectives are critical to learning sustainability in STEM classrooms [6]. Most accredited curricula require group-based engineering projects [7] and an interdisciplinary approach to engineering design that includes social as well as technical aspects [8], [9] There is a clear need for both qualitative and quantitative literacy about climate change for undergraduates in an interdisciplinary context to increase public knowledge and understanding of climate change [10]. There are calls in the literature for participation of nontechnical majors in sustainable engineering [11], multidisciplinary learning experiences [12], integration of sustainable development in engineering education [13], and a focus on integrating multiple perspectives on sustainability into higher education [14].

The technique of Life Cycle Assessment (LCA) started to develop in the 1970s, where researchers were typically trying to quantify the amount of energy needed in alternative processes using a life cycle inventory (LCI). It has since developed in the 21st century into a standard method for quantifying environmental sustainability and has even extended its use to include multiple stakeholders and social impacts as decision criteria [15]. There is extensive work in the education literature on using LCA as a learning tool for engineering students; Burnley et al. emphasize the method as an "ideal opportunity for students to develop and apply both quantitative and qualitative skills" [16]. A sustainability course including juniors and seniors of various engineering majors incorporated LCA to enhance nontechnical perspectives in students' engineering practices [17]. A module offered to civil engineering students in Australia demonstrated that students had misconceptions about environmental sustainability before taking the course but rated it as an important issue afterward [18]. Using LCA for sustainable and renewable energy education provides "better integration of the economic and social dimensions into comprehensive sustainability of renewable energy systems" [19] and is a natural way to introduce the concept of interdisciplinarity to students due to the necessity of considering multiple perspectives and stakeholders in the assessment process.

Our course is unusual in that the cohort of students is of mixed discipline; students were enrolled from The Cooper Union's School of Architecture, School of Art, and School of Engineering. This required conscious effort in developing the level of the content presented and offering information in an understandable way to students who have not taken college-level math or physics. Previous authors have built science and global sustainability courses for nonscience majors to broaden understanding of technical (energy, climate change, etc.) and nontechnical (economic, ethical, etc.) subjects and reported that students developed confidence discussing scientific concepts after the course [20], [21]. Some studies were focused on civil and environmental engineers [22], [23], [24], some were courses/modules on sustainability for liberal arts or architecture majors [25], [26], [27], while others have investigated student difficulties learning about environmental concepts like the carbon cycle in a biology courses for all majors [28]. All these authors have pointed out the difficulties in teaching students of different majors and identified important differences between cohorts.

The body of educational research on the climate crisis, sustainability curricula, and courses on environmental justice is growing. Previous authors have offered courses focused on challenge-based [29], experience-based [30], and laboratory-focused [31] approaches to teach sustainability and sustainable development, but our course is unusual in that it attempted the subject in an entirely remote format. There is increased recognition of the need for interdisciplinarity in approaching the topic of sustainability and alternative energy technologies in engineering coursework; our work adds to the literature by presenting and assessing an interdisciplinary course offered across majors and schools. Further, by assessing student interest and proficiency in course topics according to major, we can understand how these differences affect the interdisciplinary environment.

Course Overview

Our aim in offering the course was to meet several needs: a need for students to learn about sustainability as a broad concept, a need to understand our current global pollution epidemic and how it relates to climate change, an opportunity to investigate alternative energy technologies as a solution to our rapidly rising carbon emissions, and to give our students a forum to discuss these issues with students of different majors and backgrounds in an interactive, discussion-focused way. We assumed little science or climate change history background, though we were cognizant of the different preparation in course topics for students of different majors.

There are four primary sections of the course:

1. Sustainability and Climate Change
2. Basics of Alternative Energy Technologies
3. The links between food, fuel, and carbon pollution, and
4. Life Cycle Assessment of Environmental Impacts

We first introduce the concepts of sustainability [32] (the ability to exist for a “long time” without loss of function or undue impact on the environment) and sustainable development [33] and then consider how these concepts relate to climate change. We then cover the science behind the greenhouse effect [34] and the history of how knowledge of the environmental impacts of carbon pollution evolved in the U.S. [35] Concepts like global warming potential, radiative forcing, the earth carbon cycle, our carbon budget, and planetary boundaries [36] are introduced. We then go into the history of fossil fuel technology (both for electricity and fuel/transportation), how it has evolved over time, and how it has affected Earth's climate.

The next section of the course is on alternative/renewable electricity generation technologies such as nuclear, geothermal, wind, solar, hydroelectric, biomass, etc. [37], comparing them to how electricity has traditionally been generated at scale. Students are asked to discuss potential social and environmental consequences of implementing these technologies and how they relate to the culture, politics, and design of the built environment in their country/region of operation. This material builds into the first group project, where students write a report and give a presentation to the class on a recently planned or built electricity generation facility of their choice, focusing on both on the technical details of the plant and the cultural and geographical context of the project.

The textbook we chose is Our Energy Future [38], which addresses both the fundamentals and science behind alternative energy for electricity generation and alternative fuels for transportation. In covering alternative transportation fuels, we cover the link between conventional food production and fossil fuel use and the disruption of the nitrogen cycle by ammonia-derived fertilizers. The course also covers carbon dioxide removal (CDR) technologies including enhanced weathering, biochar, afforestation, and direct air capture (DAC).

The final section of the course on Life Cycle Assessment [39] (LCA) which is a method for measuring the environmental impact of an object through every step of its existence. We begin LCA with the basics of material and energy balances and explain the importance of the laws of conservation of mass and energy to engineering calculations. We end the class by giving students perspective on the different stages in production that can drive environmental impact (particularly energy use and raw material extraction) and discuss minimizing environmental impact via their second project presentations.

Student Learning Outcomes

Our goals for student learning were most related to ABET outcomes two through five, especially 2 and 4:

2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3. an ability to communicate effectively with a range of audiences
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives

Particularly, we wanted to give students information they could use to evaluate “public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors” as well as “the impact of engineering solutions in global, economic, environmental, and societal contexts” [40]. Though not every student in the class was an engineer, these outcomes are valuable for all students. Student learning outcomes were outlined at the beginning of the course and assessed in homework, quizzes, and projects - by completion of the course, students should be able to:

1. Explain what sustainability is and how it is affected by time, geography, and people
2. Understand the history of climate change and how it impacts us currently
3. Define different forms of energy and explain how energy is converted into electricity or other forms of work
4. Explain the technological, social, and economic impacts of switching to different alternative energy technologies from more common fossil fuel based processes
5. Explain what a life cycle assessment is and what needs to be considered to create one
6. Apply basic material and energy balances to quantifying environmental impact of a product or process using an LCI
7. Use LCA as a tool to compare two alternative processes or products

The course is focused around two project assignments, each asking students choose their own topic and present their findings to the entire class. There were also two quizzes and three homework assignments to reinforce topics from class and to help the students with the steps in the projects. The first project was to investigate an energy (abbreviated as E in Table 1) generation facility that is currently being proposed, is in development, or has been recently constructed in a specific region in the context of the geography, impacted communities, and current energy infrastructure in the area. We asked students to submit a group proposal, give a brief presentation to the entire class on the facility they investigated, and complete a report of at least 5 pages addressing the technologies, impacts, stakeholders, and local geography of the facility. Project two asked students to choose two particular products or process alternatives (the classic example is comparing paper and plastic bags) and investigate their different inputs, wastes, emissions, and social impacts. The work products for the second project were a short project proposal and a 5-minute video presenting their results.

Assignment	Learning Outcomes	Individual or Group
Quiz 1: Sustainability and Sustainable Development	1	Individual
Homework 1: Climate Change History	2	Individual
Quiz 2: Forms and Units of E and Alternative E Technologies	3,4	Individual
Homework 2: Tracking E consumption	3,4	Group
Project 1 Proposal	4	Group
Project 1 Presentation	1,3,4	Group
Project 1 Powerpoint Slide	3	Group
Homework 3: Introduction to LCA	5,6,7	Group
Project 2 Proposal	5	Group
Project 2 Video	5,6,7	Group

Table 1: Assignments, Learning Outcomes, and Average Scores

We assessed course-level student learning outcomes using these assignments in Table 1; we assumed that a score of 80% or higher on an associated part of each assignment indicated satisfactory achievement of an outcome. The average scores for the class on each assignment were above 80%, indicating that significantly more than half the students achieved each of the seven outcomes. In addition, we had students reflect on their skills at the beginning and end of the course in a post-course survey.

Course Assessment/Results

We surveyed students at the end of the semester to understand how they felt about various aspects of the course, including their progress in meeting learning objectives, their level of interest in course topics, and how effective they viewed our teaching techniques. Every major in the college was represented in the course; there was 1 architect, 5 artists, and 16 engineers (2 civil, 10 chemical, 3 electrical, and one mechanical). The survey was delivered through Microsoft Forms and 21/22 of the registered students completed the survey. Both quantitative and qualitative responses were collected, and quantitative responses were measured using a 5-point Likert scale.

Our students reported being interested in the course material at the beginning of the course. Students were asked to rate their initial and final interest levels in the 4 primary course topics and given choices from 1 (no interest at all) to 5 (strongly interested), they had an average reported interest level of 3.49 out of 5.00. This value was relatively similar across all majors (3.45 for engineering students and 3.58 for art/architecture students). Excluding the topic of LCA, the average initial level of interest in course topics was 3.78, indicating that other elective course offerings in these subject areas would likely draw student interest.

There were significant differences in interest level per course topic according to student major. As shown in Figure 1, engineering students were initially more interested in "Technology related to alternative energy" (4.33 out of 5.00) compared to art/architecture students (3.67) and engineering students were less interested in "Cultural or political issues related to alternative energy or sustainability" (3.27 out of 5.00) compared to art/architecture students (4.00). However, by the end of the course, these reported differences in interest levels between majors were lower; art/architecture students had the most significant gains in interest for "Technology related to alternative energy" (27% increase compared to an 8% increase for engineering students) and there was no measured difference in interest level between engineering students and art/architecture students in this topic by the end of the course. Similarly, although art students had a higher pre and post level of interest in "Cultural or political issues related to alternative energy or sustainability", engineering students had a more significant increase in interest pre/post (22% increase in interest for engineering students compared to a 13% increase for art/architecture students). These results seem to show that a student's major was indicative of initial level of interest in a topic, but that their interest levels became more closely aligned by the end of the course.

Overall, student interest in all topics increased during the semester. The average reported student interest level in the course topics at the end of the course was 4.26 out of 5.00, which is extremely high. This also was a significant gain over the average initial level of 3.49. The lowest level of reported initial interest was in the topic of LCA (average rating of 2.62 out of 5.00 across all majors); LCA also had the highest level of reported interest increase, up 53% to 4.00 for all students. This is likely due to students being unfamiliar with LCA before enrolling.

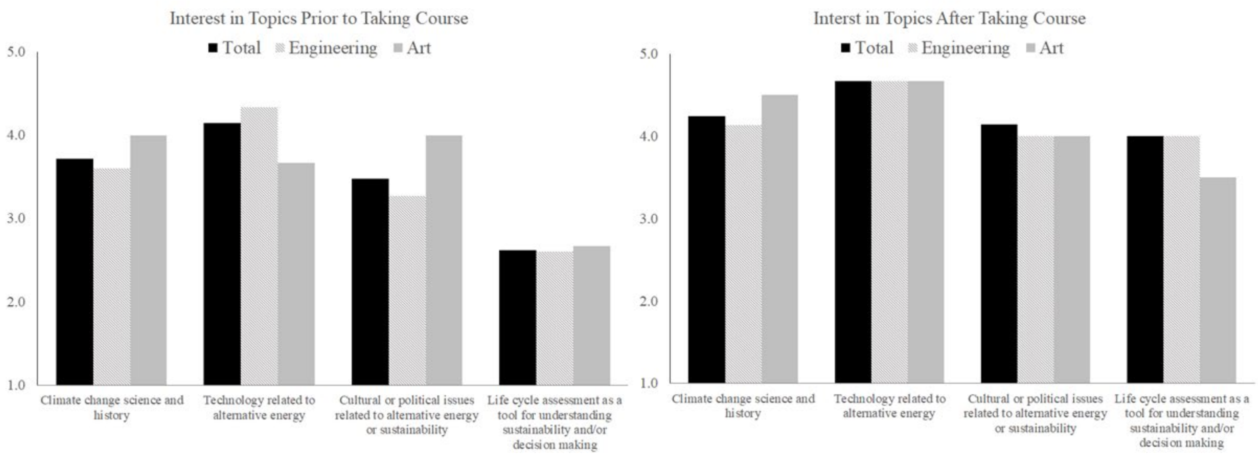

Figure 1: Students reported interest in course topics pre/post course, measured on 5-point Likert scale (1 = no interest at all, 5 = strongly interested).

Reported proficiencies at the beginning of the semester varied significantly between majors. As shown in Figure 2, students were asked to reflect on their ability in each of the 7 learning outcomes on a 5-point Likert scale. Engineering students reported higher initial proficiency on technical outcomes, such as outcome 3 (average value of 4.40 for engineering students compared to 2.50 for art/architecture students). Art/architecture students reported higher initial proficiency on less technical outcomes, such as outcomes 1 and 2 (average values of 2.43 for engineering students compared to 3.42 for art/architecture students). According to a t-test analysis (using $p < 0.1$), these differences between the majors were significant for four of the seven outcomes at the beginning of the course, whereas at the end of the course, they were significant for only one outcome (3). The differences in both the reported interest and proficiency between students of different majors demonstrates the importance and potential of peer-to-peer learning in an interdisciplinary course.

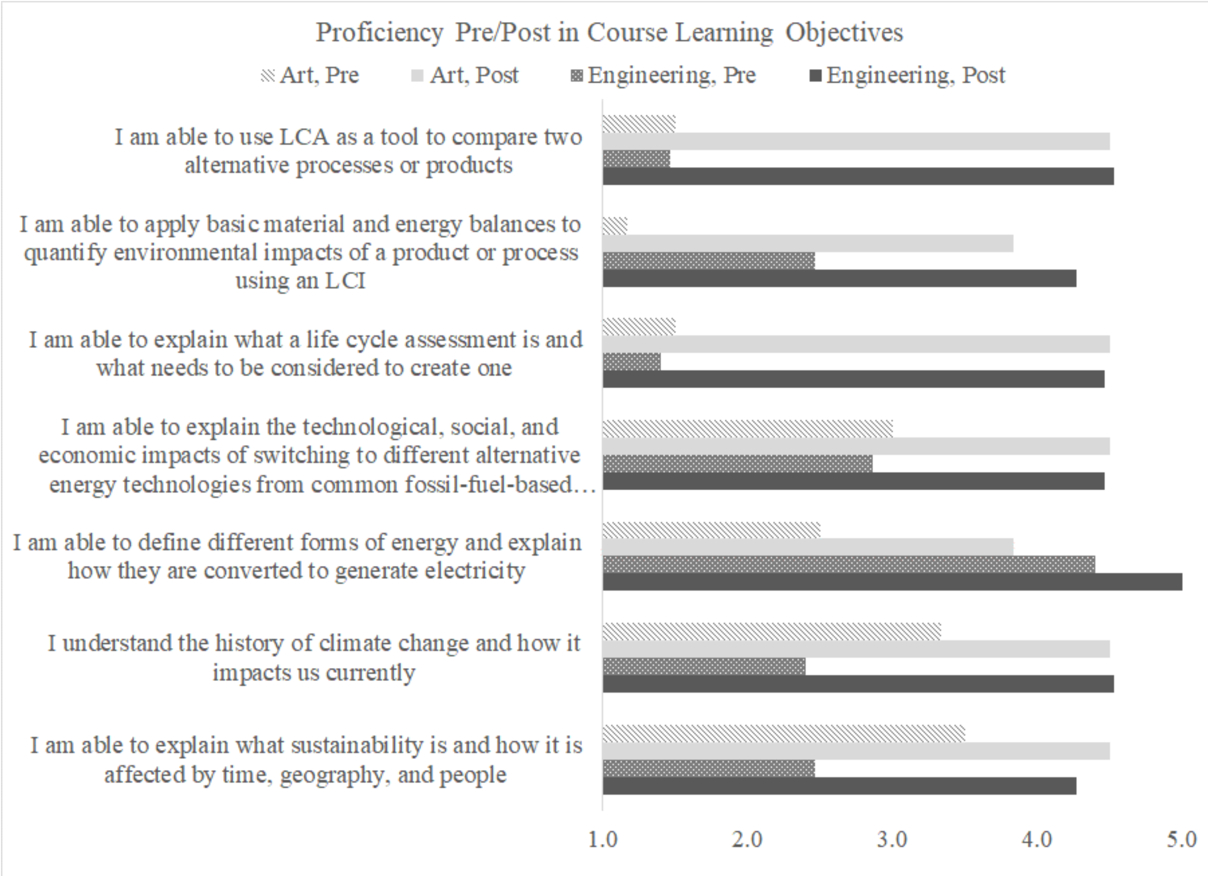

Figure 2: Students' Reported Proficiency in Skills Related to the Course

Generally, students felt that by the end of the semester they had met all learning outcomes in the course, with an average score of 4.45 out of 5.00 across all outcomes. This was in line with student achievement on graded assignments.

Students reflected in the survey on the teaching techniques used in the virtual environment and on course assessments using a Likert scale from 1 (not at all helpful) to 5 (very helpful). Most students (62%) felt that the teaching techniques were either helpful or very helpful and a majority of students (57%) felt that the course assessments were either helpful or very helpful to their learning. Students of different majors had similar feelings about the usefulness of both pedagogical tools and assessment. They found the content delivery via annotated slides over Zoom the most useful, with 95% of students saying it was either "helpful" or "very helpful." Surprisingly, active learning activities used to break up the lecture were rated lower than the lecture delivery (71% said these were either "helpful" or "very helpful"). When asked what could be improved about the course, one student responded "breakout rooms with groups during class didn't add much to the course for me." The chat function in Zoom was used as the primary differentiation activity during lecture, to provide additional resources and for individual questions; this was found to be more useful for art/architecture students ($p = 0.091$). These results demonstrate the importance of incorporating differentiation techniques, particularly in a course with students of different majors that have different initial levels of proficiency and exposure to course topics.

Students reported very different comfort levels with group work when they started the course. As shown in Figure 3, engineering students reported being more comfortable than art/architecture students (p = 0.027). We hypothesize that the differences in comfort level were due to the higher amount of group work the engineers have in their other courses. In qualitative responses about the course, an art/architecture student remarked that it was "the most group work they had done [in college]." A significant amount of course assessment was group work and most lectures had in-class group activities. By the end of the semester, despite the initial differences, students had similar levels of comfort with group work (no statistical significance, p = 0.252). The results demonstrate that students from different majors bring both different skills and pedagogical experiences to an interdisciplinary classroom. Another example of this is in student responses about the effectiveness of class discussion. As shown in Figure 3, engineers felt that the class was better at inspiring discussion than art/architecture students. All engineering students reported that the class did "well" or "very well" at inspiring discussion; engineering students reported an average of 4.60 out of 5.00 compared to 3.83 for art/architecture students (p value = 0.003). We suspect that this may be because engineers are used to less discussion in their courses; as evidence, in the qualitative feedback about how the course was different from their other courses, engineers said the course "gave a greater social/political/economic background compared to most engineering courses" and another said that other courses did not address "sustainability much less the social/political/economic impacts of the work."

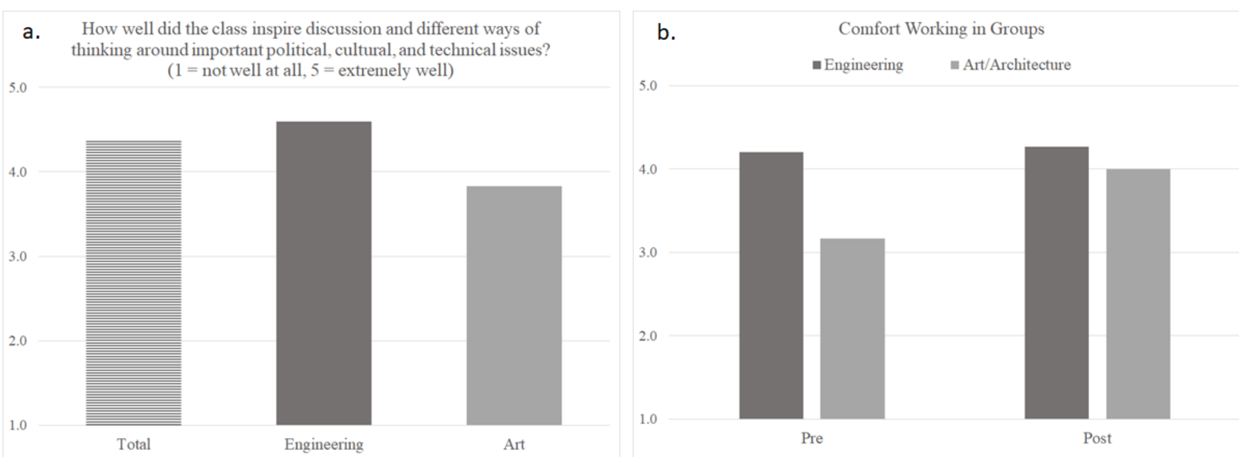

Figure 3: Average scores, measured on a 5-point Likert scale for how well the class inspired discussion (a.) and how comfortable students were working in groups (b.)

In addition to Likert questions, students were solicited for open-ended feedback about the course, including how interdisciplinary it felt, how it was similar or different from other courses, and what aspects could be improved. Students responded that the course was different than other courses due to the diverse cohort of students, the focus on working in groups mixed in major and year, the diverse set of course topics, and the balance of some familiar and some unfamiliar topics. One student remarked: "The way the content was presented was easy to follow and I felt like no matter what background I was from I could have understood. Coming from an engineering background did make it more enjoyable since I could think about topics in the context of my other courses." When asked how the course could be improved, students suggested that course content be more related to art and architecture and/or recommended an increased focus on the social and cultural aspects of climate change.

Conclusions

Climate change is the defining issue of our time and presents many ethical, social, cultural, and technical challenges; it is important not only that students know this, but also that its impacts on people will be unequal. Our survey results show that students gained an increased appreciation and understanding of alternative energy technology needed to address the climate crisis and the ethical trade-offs in energy system choices. Because these topics are both essential to all students' future and interdisciplinary, studying student interest and proficiency according to their chosen course of study helps identify how student differences affect their learning. We found that engineers were more interested in technology and artists/architects were more interested in cultural and political issues at the beginning of the course, but that there was no difference in interest level across course topics between majors afterwards.

Despite the limitations of a remote format, student learning and stated interest in the course was very high; most students achieved our stated outcomes (average scores were above 80% for all assignments) and student interest rating averaged 3.78 out of 5.00 (indicating supporting courses would likely draw student interest). Additionally, student interest in all topics for all majors increased over the semester; students reported gaining a greater appreciation for the climate crisis and how to engineer for sustainability. We saw a reported topic proficiency gap by major which closed over the semester and that major was correlated to comfort with group work (engineering students more comfortable than art/architecture students). These differences in comfort level may be due to engineers doing more group work in other classes, but by the end students had similar levels of comfort with group work. Students from different majors bring both different skills and pedagogical experiences to an interdisciplinary classroom and it may take time for them to adjust.

Survey responses were overwhelmingly positive; they enjoyed the diverse cohort, set of topics, focus on group work, and the projects. Students liked active discussion via Zoom, especially art/architecture students, potentially demonstrating the importance of incorporating differentiation techniques for students of different initial levels of proficiency and exposure to course topics and indicating that students farther outside their comfort zone may appreciate more differentiation.

We plan to offer this course again in the future as an interdisciplinary course to students of all majors with a focus on discussion, group work, and social/political/cultural topics related to sustainability and the climate crisis.

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