AC 2007-318: INTERDISCIPLINARY TEAM TEACHING: LESSONS FOR ENGINEERING INSTRUCTORS FROM A CAPSTONE COURSE IN ENVIRONMENTAL STUDIES

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Interdisciplinary Team Teaching: Lessons for Engineering Instructors from a Capstone Course in Environmental Studies

Abstract

The capstone course teaches students to analyze global environmental issues, resources, and human activities with a systems approach based on scientific, economic, political, social and ethical perspectives. Such an intrinsically multifaceted subject demands interdisciplinary treatment. To deliver the interdisciplinary treatment, the course uses diverse faculty teams comprised of faculty from fields in the natural and social sciences, engineering, and business. This work describes the interdisciplinary team teaching strategies adopted for the course and how they evolved with subsequent offerings of the course. We present assessment data measuring how well students achieve course objectives. Finally, experience gleaned from this course for non-majors has produced ideas for lessons engineering instructors can apply to their own courses.

Introduction

The context for this work is a course titled *The Global Environment*. The course teaches students to analyze global environmental issues, resources, and human activities with a systems approach based on scientific, economic, political, social and ethical perspectives. The course forms the capstone experience for the Minor in Environmental Studies.

Perhaps what will most fascinate engineering faculty is how the course integrates non-technical content with science and technology. The lecture portion of the course mixes technical and non-technical points of view using multimedia presentations by faculty from various areas of expertise and having the students complete a series of reading and writing assignments. The activity portion of the course brings together students from various disciplines in a term project applying problem development and analysis to improve real environmental situations. For the project, students select one global environmental issue and a local manifestation of this issue; analyze relevant resources; develop technical recommendations to address the issue at the local level; perform an economic analysis to estimate costs and benefits of implementing the technical recommendations; and develop political recommendations regarding strategies necessary to implement the technical recommendations. The preceding steps constitute the milestones in the project, allowing students to receive timely feedback prior to project completion.

The course webpage, http://www.ee.calpoly.edu/~dbraun/courses/TGE/UNIV350.html[1], contains valuable course resources in addition to those described in this work.

Learning Objectives and Outcomes

Conceived as the capstone course for the Minor in Environmental Studies, the course seeks to achieve an ambitious scope of objectives; perhaps too ambitious. The course syllabus describes the course goals:

> "This interdisciplinary course enables students to examine global environmental issues from scientific, economic, political, social, and ethical perspectives. The interdisciplinary subject matter challenges one to assimilate and integrate facts, ideas, and concepts from different and possibly unusual perspectives without becoming frustrated. Systems thinking enables students to process, integrate, and interrelate these facts, ideas, and concepts effectively. Environmental problems are complex and require us to see problems from various often conflicting viewpoints. This capstone course provides the opportunity to examine recurring themes of ideas and relationships without having to become a specialist in every subject. Group activities involve students from various colleges in applied problem development, analysis, and methods to improve real environmental situations. The course encourages you to combine your knowledge and experience with that of others."[1]

The catalog description captures the course more tersely:

> "An interdisciplinary investigation of how human activities impact the Earth's environment on a global scale. Examination of population, resource use, climate change, and biodiversity from scientific/technical and social/economic/historical/political perspectives. Use of remote sensing maps. Sustainable solutions."[1]

Ideally, students completing the Environmental Studies Minor would enter *The Global Environment* course after taking one or more courses in each of the areas required by the Environmental Studies Minor:

- Biology and ecology;
- Earth science;
- Energy and pollution;
- Social, political, and ethical issues;
- Environmental planning, management, and sustainability.

When utilized in this manner, the course could form a valuable capstone experience building on the varied skills and multidisciplinary interests of the students. More typically, students take *The Global Environment* course to fulfill a general education requirement, where few have completed courses in all of the areas required by the Environmental Studies Minor. Having a large fraction of general education students in the course may increase the number of different majors the students represent (more than 20 different majors in each of the last two offerings of the course to class sizes of 59 and 70 students) and thereby enhance the multidisciplinary nature of the course. A large fraction of general education students may similarly dilute the capstone experience.

The syllabus distinguishes theoretical outcomes from applied outcomes:

"EXPLAIN: After taking this class, students will be able to explain . . .

- How and where human activities impact the earth's environment on a global scale.
- Interconnections among global issues of population, resources, climate, and biodiversity.
- How environmental issues have both scientific/technical and social/political/ethical/economic aspects.
- Scientific principles underlying global measurements and mapping technologies.
- Conversion of energy resources from raw materials to end uses.

DO: After taking this class, students will be able to . . .

- Access, interpret, and use global maps.
- Evaluate evidence and information about environmental issues.
- Integrate and synthesize information from multiple disciplines.
- Apply problem-solving strategies using techniques from multiple disciplines to complex problems involving both natural and human systems.
- Work with others from different backgrounds to pose and evaluate resolutions to complex problems."[1]

The course aims are intentionally broad, interdisciplinary, and integrative in nature. Providing exams, papers, activities, and the course project focus student and instructor attention to specific expertise in a variety of topics. One theme pervading the course is the need to base knowledge and decision making on *evidence*. The project assignments, in particular, stress the theme of evidence.

1.5 weeks	Overview of global environmental issues, the tragedy of the commons
1 week	Physical, biological and environmental systems
1 week	Political and economics systems
0.5 week	Environmental ethics
1.0 week	Energy resources
0.5 week	Climate change and global warming
1.5 weeks	Water, food and agriculture resources
0.5 week	Biodiversity and extinction
2.5 weeks	Sustainable strategies

Table 1 – Lecture topics in *The Global Environment* course Fall, 2006.[1]

Table 1 lists the general topics covered by the course and indicates the approximate calendar time devoted to each topic during the latest offering. The course relies heavily on two major strategies to do justice to the general nature of the course and make the specific connections between the various course topics: multidisciplinary team teaching and an interdisciplinary group project. Each instructor meets with their group of fewer than 35 students weekly during an activity session. Most tasks in the activity sections revolve around components of the group project. Students from all activity sections meet twice weekly with all instructors for three hours of lectures.

Multidisciplinary Team Teaching

To distinguish interdisciplinary from multidisciplinary efforts, we turn to Paul and Anne Ehrlich:

> "Multidisciplinary teams are composed of individuals each working separately on his or her "piece" of an overall problem. Needed instead are *interdisciplinary* teams—groups of people who focus not on "their" component of a problem but collaboratively on the entire problem through the lens of their particular expertise."[2]

An interdisciplinary team teaching approach makes such an ambitious course feasible in a manner one individual instructor could unlikely achieve working independently. When comprised of faculty from different disciplines, the team infuses the course with the broader knowledge base available from the distinct disciplines each faculty member represents. While striving to teach the course using interdisciplinary methods, instructor teams bring at least multidisciplinary approaches into the classroom. Table 2 lists the compositions of faculty teams who teach the course. Teams form by consensus after careful consideration of potentially compatible faculty, based on subject expertise and who volunteers to teach the course during a given quarter. Each team as a whole makes available more scholarly expertise and physical energy to drive and inspire the course than one instructor could. The members of the team can delegate tasks to each other to optimize effort and provide feedback to each other to improve quality and correct errors. The team demands unique contributions from each instructor and consequently allows each instructor to learn from the team in an unusually meaningful manner. Some team members view participation on such teaching teams as the most intellectually stimulating and rewarding teaching experiences available, not to mention time consuming.

Our teams map out and prepare lectures to deliver a significant portion of lecture materials via the pedagogy of multimedia instruction. Animated PowerPoint slides, short video clips embedded in PowerPoint slides, longer video clips on DVD, and materials from internet sites improve student retention and address the learning style of visual learners.

	Disciplines of course instructors	Enrollment
Spring 2004	Physics, Soil Science	62
Spring 2005	Business, Physics, Political Science, Soil Science	55
Spring 2006	Electrical Engineering, Political Science, Soil Science	70
Fall 2006	Electrical Engineering, Political Science, Soil Science	59
Spring 2007	City and Regional Planning, Physics (Planned)	66

Table 2 – Multidisciplinary instructor teams for *The Global Environment* course

Useful caveats can guide team teaching to proceed more effectively. Joshua Landy and Lanier Anderson succinctly advise such teams to obey 10 commandments:

1. Thou shalt plan everything with thy neighbor.[3]
   Planning for the course offering by the latest team began with meetings roughly weekly starting the quarter prior to the course offering. During the quarter, instructors met at

least once per week in face-to-face meetings. In our experience, the team teaching requires a greater investment of time than managing a course individually.

2. Thou shalt attend thy neighbor's lectures.[3]
   Each instructor attends each lecture, barring unusual events. During most meetings of the entire class for lectures, at least two instructors run portions of the meeting individually or jointly.
3. Thou shalt refer to thy neighbor's ideas.[3]
   Such references become easier and more frequent during subsequent course offerings with the same team of instructors.
4. Thou shalt model debate with thy neighbor.[3]
5. Thou shalt have something to say, even when thou art not in charge.[3]
6. Ye shall apply common grading standards.[3]
   Agreeing on such standards requires hard work, and it pays off. Students receive rubrics for most course assignments with the assignment, available on-line.[1]
7. Thou shalt attend all staff meetings.[3]
8. Thou shalt ask open questions.[3]
9. Thou shalt let thy students speak.[3]
10. Thou shalt be willing to be surprised.[3]

We endorse the commandments and attempt to follow them. We probably succeeded more with commandments 1-3 and 6-10 than with 4 and 5. Because of the significant time commitment required by faculty, it is helpful to have support from campus administrators for such interdisciplinary activities. At California Polytechnic State University, support for interdisciplinary courses has improved from enthusiastic lip service a few years ago to actual financial support in terms of compensating faculty for much of their teaching time. The administration also facilitates the scheduling difficulties involved with synchronizing the schedules of faculty housed in different departments and even different colleges. Our institution is a primarily undergraduate institution with heavy teaching loads and incomplete public support. Add in the politics of a public school, and the difficulties mount. Overcoming such bureaucratic hurdles greatly improves the ability to offer such courses, and it did require years of efforts by dedicated faculty, who often pursued their interest in interdisciplinary teaching by volunteering their time.

The story of how the course made its way into the campus catalog illustrates the bureaucratic obstacles involved. At our institution, faculty compensation for instruction usually arrives via the college housing the course. Having a faculty member from one college receive compensation for a course taught in another college typically requires some type of agreement between relevant deans and/or department chairs. To enable the course to use multidisciplinary teams of instructors from different colleges, we initially proposed adopting the course and cross-listing it under each college. Accomplishing this task required the approvals of curriculum committees in six colleges, a concurrent and somewhat iterative process involving minor revisions to the course proposals. In time, all six colleges added the course—with the same course number, 350—to their catalog listings, and the course has entries in the colleges of Agriculture, Food and Environmental Sciences; Architecture and Environmental Design; Business; Engineering; Liberal Arts; and Science and Mathematics. After the first course offering in 2004, our administration sought to encourage more multidisciplinary team-taught courses, and address university-wide learning objectives (e.g., diversity, environmental literacy, sustainability, etc.). To streamline the bureaucratic difficulties we faced, the provost offered to pay for the course directly and list it in the catalog under a new category of multidisciplinary courses, University Studies.

Realistically, administrative support does not possess infinite patience or infinitely deep pockets. Table 2 summarizes the student enrollment numbers. With a rough requirement of 35 students per instructor, present demand doesn't justify offering the course with teams of three or four instructors. Unless demand increases for the course, faculty volunteer their time, or an angel investor appears on the scene, the course will return to teams of two instructors. If the effectiveness of faculty teams as a function of number of group members mirrors the effectiveness of student groups, then teams of three or four faculty prove more valuable than smaller or larger teams.[4]

Interdisciplinary Group Project

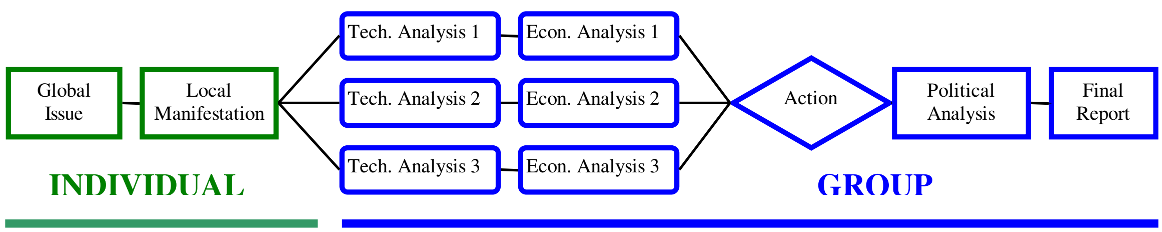

Figure 1 – *The Global Environment* course group project from Fall, 2006.[1]

Most work for the group project revolves around the activity sections. The group project proceeds in phases, each involving a written assignment. Figure 1 depicts the phases of the project. In the first two steps, students work independently to select one global environmental issue and a local manifestation of this same issue, local to the university campus, town, or county. Based on the issues selected by students and possibly other factors to improve the quality of the group projects, the instructors assign students to groups. Students work in the assigned groups on the subsequent phases of the project. For the technical analysis, each group analyzes relevant resources and develops three distinct technical recommendations to address the issue at the local level. For each technical approach, each group performs an economic analysis to estimate costs and benefits of implementing each technical recommendation throughout the life cycle of each recommendation. Based on their technical analyses, economic analyses, and other considerations such as ethical or social issues, each group selects one recommendation on which to act. For the selected approach, the group performs a political analysis using the Prince System[5] and develops political strategies necessary to implement the technical recommendations. The project concludes with a final written report, and each group makes an oral presentation to the class. Local issues addressed by projects include air pollution generated on campus by various vehicle fleets, campus energy use, methane emissions from landfills or livestock waste lagoons, surface and ground water pollution, local deforestation and threats to biodiversity.

The Gantt chart in Figure 2 depicts the timing of the course, and the center of the figure contains the tasks associated with the group project. The Gantt chart emphasizes how the timing of project phases permits students to receive feedback assignments in time to use the feedback in later phases of the project and in the final project reports and presentations.

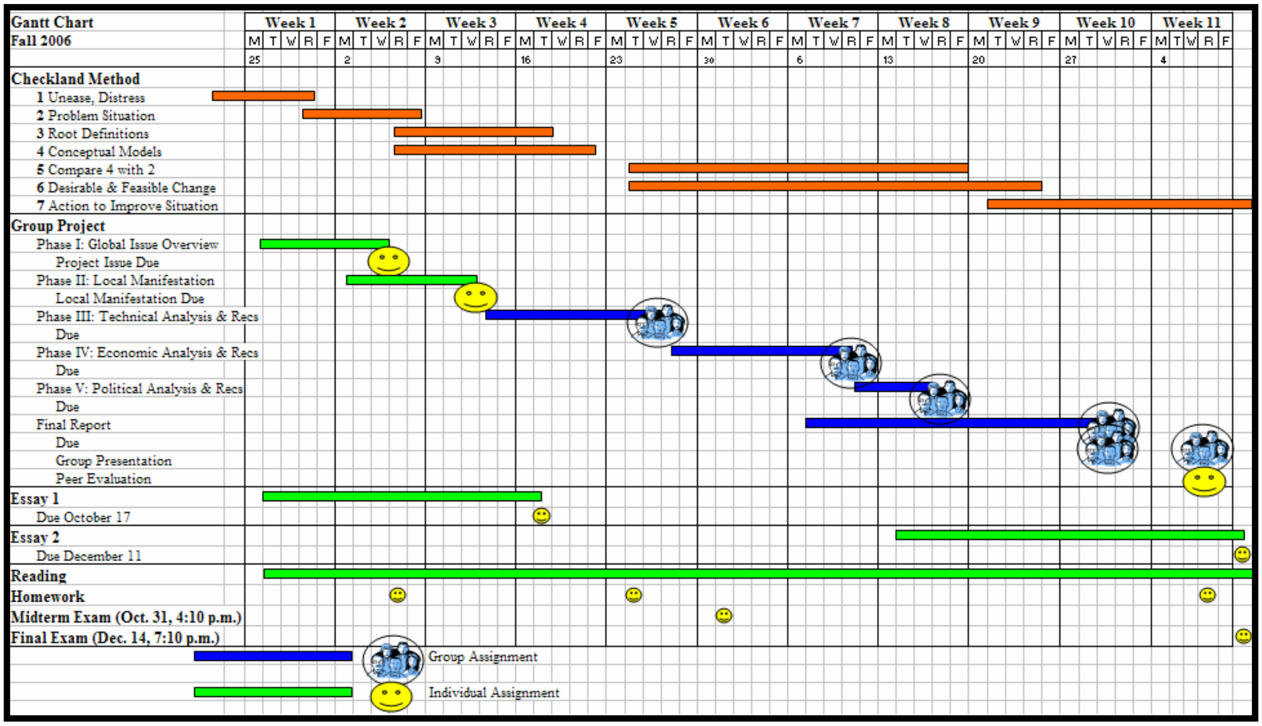

Figure 2 – *The Global Environment* course Gantt chart from Fall, 2006.[1]
Green bars represent individual tasks, and blue tasks represent group tasks.

Traditional Assignments

In addition to the group project, students complete traditional assignments individually. Assignments include reading, homework, two essays, one midterm exam, and a final exam.[1] For the first two offerings of the course, course readings followed a strategy of having students read the environmental science literature directly from the original source articles. To make it easier for students to access and organize course concepts, subsequent offerings used a nice environmental textbook, *Environmental Science* by McKinney & Schoch,[6] supplemented by original sources.[5,7-12] After reading the objectives, specific outcomes, and Figure 2, some readers may sympathize with student comments describing the course workload as too heavy.

Assessment of Student Learning

Before and after the Fall 2006 quarter, a survey measured students' opinions about their abilities to perform each of the course objectives and outcomes. Table 3 lists the questions used in the surveys. Questions 1-25 have students rate their own abilities to perform each of the following objectives using the following pseudo-Likert scale: None (0); A little familiarity (1); Good (2); Very good (3); Expert (4); Don't know, Not applicable. To quantify the responses, each response receives the value shown in parentheses, so scores range from 0 to 4. Responses of Don't know and Not applicable are ignored. Questions 26 and 27 require short answers, so a rubric permits quantifying the responses: +1 for each correct phrase mentioned in a response and -1 for each unrelated item in the list. The maximum score assigned is 5, even for lengthier correct responses. We assign no negative scores and ignore unanswered questions. Scores on Questions 26 and 27 may range from 0 to 5. The survey was administered using the Blackboard Academic Suite to students registered for the course. The pre-course survey questions averaged 30 respondents, and the post-course survey averaged 16 respondents. Means of the pre- and post-course responses appear in Table 3 and Figure 3. Seeking statistical significance at the 0.05 level, we label and emphasize with yellow shading in Table 3 $P < 0.05$ as significant (*), $P < 0.01$ as highly significant (**), and $P < 0.001$ as extremely significant (***). No yellow shading indicates a P-value above 0.05.

For all learning objectives assessed via the survey, students rate their post-course knowledge higher on average than their pre-course knowledge. Even the direct measures (questions 26 & 27) show improvements, though question 27 lacks statistical significance. Results for five questions (3, 5, 20, 21, & 27) are not statistically significant. All other questions observe statistically significant differences ($P<0.05$) via an unpaired t-test between the means of the pre- and post-course responses. Since calculating the mean values assumes linear weighting of the scores on the opinion scale, and the descriptions (Good, Very good, etc.) don't necessarily translate linearly into scores, the magnitudes of the differences between the pre-course and post-course means—reported as Delta in Table 3—deserve relative interpretation rather than absolute.

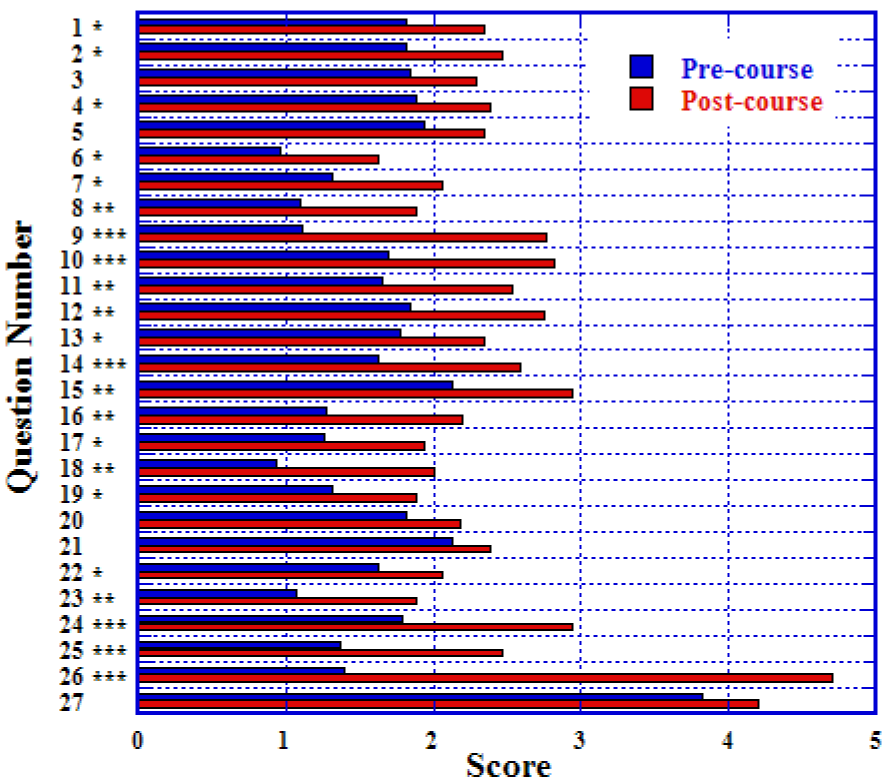

Figure 3 – Pre- and Post-course survey results. *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$

		Mean			
Explanation, analysis, and thinking skills:	None (0) to Expert (4)	Pre	Post	Delta	P
1	Apply systems thinking concepts to analyze environmental issues.	1.81	2.35	0.54	*
2	Explain how environmental issues have scientific/technical and social/political/ethical/economic aspects.	1.81	2.47	0.66	*
3	Evaluate evidence and information about environmental issues.	1.84	2.29	0.45	
4	Integrate and synthesize information from multiple disciplines.	1.88	2.38	0.50	*
5	Analyze an ethical dimension of an environmental issue.	1.94	2.35	0.42	
6	Explain the scientific principles that underlie global measurements and mapping technologies.	0.96	1.63	0.66	*
7	Explain renewable and non-renewable energy conversion of resources to end uses.	1.32	2.06	0.74	*
8	Explain global politics of energy resources.	1.10	1.88	0.78	**
9	Apply the tragedy of the commons concept to analyze environmental issues.	1.11	2.76	1.65	***
10	Apply the first law of ecology "everything is connected to everything else" to analyze environmental issues.	1.69	2.82	1.14	***
11	Apply the second law of ecology "everything must go someplace" to analyze environmental issues.	1.65	2.53	0.88	**
12	Analyze the environmental impacts of human activities in terms of population and consumption.	1.84	2.75	0.91	**
13	Explain the causes of global warming.	1.78	2.35	0.57	*
14	Explain the consequences of global warming.	1.63	2.59	0.96	***
15	Define the concept of sustainability.	2.13	2.94	0.81	**
Action, Doing:	None (0) to Expert (4)				
16	Develop and analyze technical approaches to address environmental issues.	1.27	2.19	0.92	**
17	Determine and compare the economic costs and benefits of environmental issues.	1.26	1.94	0.68	*
18	Develop a political strategy to implement a plan to address a local manifestation of a global environmental issue.	0.94	2.00	1.06	**
19	Apply problem-solving strategies using techniques from multiple disciplines to complex problems involving both natural and human systems.	1.31	1.88	0.57	*
20	Implement strategies to achieve sustainability.	1.81	2.18	0.37	
21	Work with others from different backgrounds to pose and evaluate resolutions to complex problems.	2.13	2.38	0.25	
22	Access, interpret, and use maps to analyze and locate environmental issues.	1.63	2.06	0.43	*
23	Measure the economic values of ecosystem services.	1.07	1.88	0.81	**
24	Measure your ecological footprint.	1.79	2.94	1.16	***
25	Decrease your ecological footprint.	1.37	2.47	1.10	***
Short answer questions:	None (0) to Max (5)				
26	List as many ecosystem services as you can.	1.40	4.70	3.30	***
27	List as many ways as you can to decrease your ecological footprint.	3.82	4.20	0.38	
*: P < 0.05 (significant); **: P < 0.01 (highly significant); ***: P < 0.001 (extremely significant)					

Table 3 – Pre- and Post-course survey results.

Conclusion

A course dealing with *The Global Environment* inherently involves concepts from a variety of disciplines. One strategy used in this work to bring together disparate disciplines relies on teams of faculty from multiple disciplines. As implemented, course instruction varies from multidisciplinary to interdisciplinary. A second strategy used in this work to bring together disparate disciplines relies on teams of students from multiple disciplines. The student teams complete a term project to address real environmental problems. This work also benefits from traditional teaching methods requiring study by individual students. Written student evaluations of the course may not indicate the students appreciate the benefits of the team teaching as much as the instructors do, but the assessment results show students think on average they achieved most of the objectives of the course. Students show improved post-course knowledge compared to pre-course knowledge for all learning objectives assessed via a survey containing 27 indirect and direct measures. 22 of the 27 metrics show improvement at statistically significant levels.

We conclude by offering the following sustainability learning outcomes for engineering instructors to consider for their courses. Without proposing an additional course for already impacted engineering degree programs, the list offers outcomes instructors might consider incorporating in extant courses. The list derives from discussions between the authors while developing and teaching *The Global Environment* course plus discussions with other faculty members. Discussions took place on campus in contexts ranging from informal coffee breaks to formal meetings regarding ABET accreditation, education methods, and campus sustainability activities. Taken as a whole, the list could fill up more than one course. If imparted judiciously into existing course modules, holistic learning efficiencies might result. This work with non-engineering students demonstrates their ability to make headway with a subset of the list.

1. Define the concept of sustainability.
    - a condition in which natural systems and social systems survive and thrive together indefinitely[13]
    - meet the needs of the present without compromising the ability of future generations to meet their own needs[14]
2. Perform life cycle analysis and design.
3. Perform design for reuse.
4. Identify and quantify the impacts of energy and natural resource consumption during a product lifecycle.
5. Identify and quantify the impacts of energy and natural resource consumption during a graduate's life.
6. Calculate the environmental footprint of a project over its lifecycle.
7. Explain the impacts of engineering projects in a societal context, including but not limited to the context of general education courses.
8. Apply systems thinking to engineering problems and projects.
9. Use international environmental management standards (ISO 14000, EMAS, etc.).
10. Define multidisciplinary teams as groups of individuals each working separately on his or her "piece" of an overall problem.[2]
11. Perform successfully as a member of a multidisciplinary team.

12. Define interdisciplinary teams as groups of people who focus not on “their” component of a problem but collaboratively on the entire problem through the lens of their particular expertise.[2]
13. Perform successfully as a member of an interdisciplinary team.
14. List the ten points in the Talloires declaration.[15]
15. Apply the goals of the Talloires declaration to engineering studies and career.
16. Predict the long-term contributions of an engineering graduate throughout their career to the state of the planet’s resources.
17. Predict the career impacts of resource consumption by an engineering graduate.
18. Consider the probability of unanticipated consequences of technical policies and strategies.
19. Articulate the concept of the Tragedy of the Commons.[10]
20. Apply the concept of the Tragedy of the Commons to current commons in engineering, including but not limited to computing power, the internet, bandwidth, other technical resources, and natural resources.
21. Articulate Commoner’s laws of ecology:[16]
    - “Everything is connected to everything else
    - Everything must go somewhere
    - Nature know best
    - There is no such thing as a free lunch”[16]
22. List the four “E”s of sustainability: Environment, Economy, Energy, Equity
23. Define ecosystem services as the benefits people obtain from ecosystems.[17]
24. Identify and measure the impacts of a project on ecosystem services.
25. Identify the internal and external stakeholders of a project.
26. Measure the impacts (costs and benefits) of a project on all present and future stakeholders.
27. Measure the economic impacts (costs and benefits) of a project on all present and future stakeholders.
28. Articulate the ethical, social, and political impacts of a project on all present and future stakeholders.
29. Develop and pursue a political strategy to implement a project.

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