Redesigning an environmental engineering fundamentals course to increase student engagement and excitement

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Abstract

A fundamentals of environmental engineering course is a common requirement in environmental engineering curricula. For many undergraduates, the course represents their initial contact with the environmental engineering discipline. However, fundamental environmental engineering courses face several common challenges. These include student populations with diverse majors and backgrounds, ambiguity about the key concepts that should be taught, and balancing breadth and depth of learning. In this paper, we describe the findings of a multi-year partnership with Distance Education and Learning Technology Applications (DELTA) to redesign the Fundamentals of Environmental Engineering course offered at North Carolina State University. The project included steps to diagnose weaknesses, survey peer institutions, define key learning objectives, incorporate new teaching practices and technologies, and assess student satisfaction and performance. Here we discuss the techniques that were employed specifically aiming to improve student engagement and discuss the results of our evaluation of course redesign effectiveness.

Keywords

environmental engineering, course redesign, student engagement

Introduction

The discipline of Environmental Engineering and Science has played a critically important role in accomplishing dramatic improvements in the quality of the air and water in the United States, while continuously evolving.1 At North Carolina State University, Fundamentals of Environmental Engineering (CE 373) is required for all students completing the B.S. Environmental Engineering degree. The learning outcomes for the course include: (1) applying quantitative methods to estimate the risks and effects of contaminants on the environment and public health; (2) using fundamental principles of chemistry, physics, biology, and engineering to analyze and design environmental processes and solutions; (3) describing key technologies and management practices available for drinking water treatment, wastewater treatment, air pollution control, solid waste management, and climate change mitigation. Major areas in which environmental engineers are active are presented.

CE 373 is typically taken by Environmental Engineering majors during their sophomore year and normally represents their first substantial contact with the discipline. The class is also designated as an area introductory course for students completing a B.S. in Civil Engineering degree. In addition, it is one of the approved concentration electives required for the Sustainable Engineering, Energy and the Environment, and Biomolecular Engineering concentrations offered

with the B.S. in Chemical Engineering degree. CE 373 is offered every year during the fall and spring semesters as a single section. Course enrollment averages approximately 80 students. The course is co-taught by two faculty members, out of a rotation of instructors, with the support of one or two graduate teaching assistants (TAs). Faculty instructors are paired according to complementary strengths and lecture topics are divided according to their areas of specialization.

Instructional and logistical challenges

The instructional and logistical challenges identified from course evaluations and discussions among rotating instructors include limited TA support and instructor time, diverse student majors and educational backgrounds, and inflexible classroom space. Balancing breadth and depth of learning is a difficulty this course shares with many engineering curricula.[2]

TA and instructor workload challenges: TA support traditionally varies from one to two 10 hours per week persons. The TAs are responsible for grading homework (HW), posting HW solutions, logging clicker responses results, and holding office hours. Considering the average class size of 80 students and about five to eight problems per HW assignment, it is impossible for the TA(s) to provide detailed grading on each problem in 10 hours per week. In addition, the workload burden imposed on instructors is considerable. Instructors coordinate lectures, prepare and update assignments and exams, hold office hours, grade exams four times per semester, and manage a large group of students. Prior to the redesign, the course format allowed limited time to explore and implement new learning practices.

Diverse majors and educational backgrounds: The diversity of student majors is another challenge in this course, which contributes to inconsistency in learning experiences and performance. Environmental Engineering students, for example, are required to take courses in chemistry and biology that teach them fundamental concepts related to CE 373. Civil Engineering majors are not required to take the same courses, which limits the depth that can be added to some topics. While the course is typically taken by Environmental Engineering majors as sophomores, a large fraction of the students from other programs are juniors or seniors. Some of these students expect to develop a strong foundation in the fundamental principles that will support them as they move deeper into environmental engineering, yet others look for a broad overview of different areas in which Environmental Engineers are active. Partially in response to the differences in student expectations and backgrounds, the course had evolved into an overly extensive description of environmental challenges, practices, and technologies with a large amount of qualitative content delivered during lectures. Assignments and exams, however, largely focus on engineering problems, even though the time dedicated to related fundamental concepts and examples in class is constrained.

Physical space: Physical space is a major challenge in this course. The class is held in a traditional, lecture-style classroom with fixed seating. Frequently, chairs are attached to the tables, preventing group-style work. Students are encouraged to work together on problems in class, but interactions are mostly limited to neighboring partners, due to the inability to easily move and form groups. It is also difficult to administer quizzes and exams to a large group of students in a crowded lecture room.

Data supporting challenges: End-of-semester evaluations highlight many of the challenges stated above. We summarize here some of the recurrent student concerns from semesters prior to the redesign: (1) too much material; (2) lack of structure; (3) few example problems in class; (4) few exam preparation materials; (5) prefer single instructor; (6) textbook not helpful. The following statements are representative of recurring comments in the student evaluations:

- "This course was very boring to me, given that I'm not an environmental engineering student."
- "This class provides an overview of many different topics. I don't think it is effective for environmental engineering students; all these topics are covered by other classes. Perhaps it should just be for non-majors."
- "Please start gearing this class to sophomore environmental engineering majors instead of civil engineering majors."
- "I was expecting the class to be a much broader overview of what Environmental Engineering is, but we seemed to have focused on the parts that the teachers found most applicable to their fields or most interesting to them...I guess I expected this class to be more introductory so I could figure out which part of environmental engineering I wanted to focus on, rather than the in depth topics we covered throughout the semester."
- "Needs to have more interactive lecture. The mini videos help but it would be more beneficial to have the students thinking through and working better questions that the clicker ones periodically through the course."

Redesigned elements

We carried out a multi-year redesign project with DELTA to improve the CE373 learning experience and increase student engagement. The project included analysis, development, and assessment phases. During the analysis stage, the following redesign objectives were determined based on past student performance and instructor evaluations: (1) strengthen students' problem-solving and critical thinking skills; (2) introduce the environmental engineering profession and increase student interest in the field; (3) explore new technologies to facilitate student engagement; (4) improve organization and delivery of course materials. All course materials were updated. The course's structure was modified to reduce the range of topics included and cover fundamental concepts at greater depth. Examples and assignments were redesigned to better reflect real engineering experiences, which has been identified as an important element in preparing engineering to face workplace problems.[3] In addition to these revisions, the elements described below were selected to pursue the redesign objectives

Problem-solving visualization and infographics: To strengthen problem-solving skills and improve attainment of the course learning objectives, interactive visualizations were developed. We identified key course concepts and the areas students commonly struggled with to select two example problems for the visual demonstrations. The problems focus on the core concepts of mass and energy balance, which are fundamental principles of environmental engineering and recurrent themes throughout the course. Visualizations were developed as interactive online resources that can used by instructors during lectures and by students outside the classroom. At each user's pace, the resources visually guide students through key steps of the problem, request input, provide feedback, and highlight key concepts. Figure 1 shows sample infographics from the visualizations created.

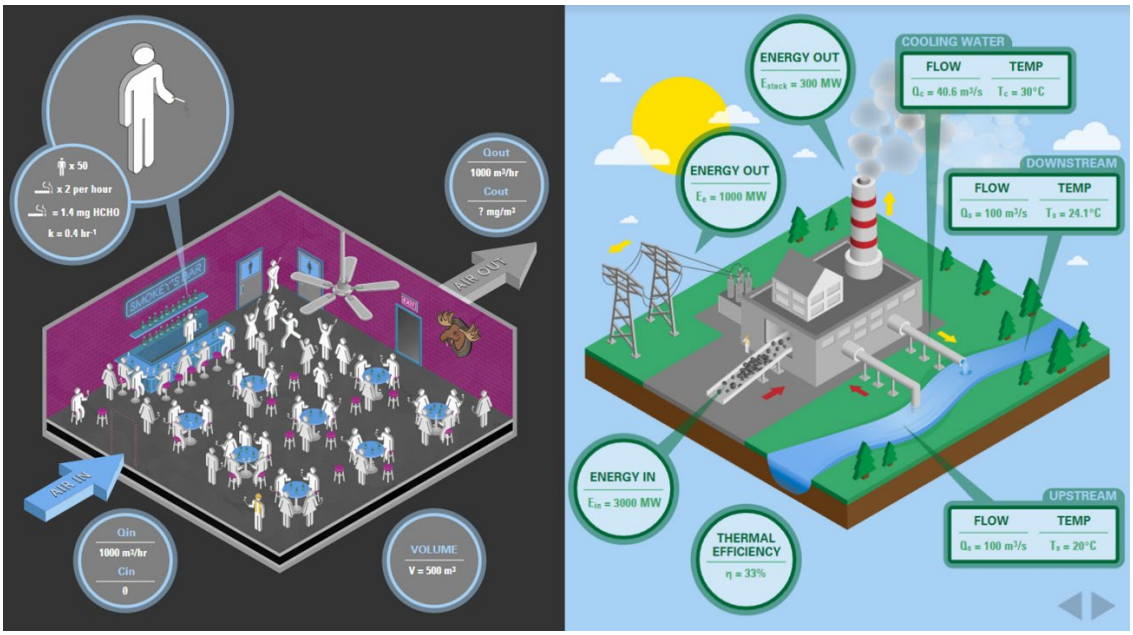

Figure 1: Sample infographics taken from the two interactive visualizations developed. On the left, students are asked to determine the concentration of contaminants from cigarette smoke in a bar. On the right, students calculate the energy output and water demands of a power plant.

Introductory environmental engineering video: A video was developed to introduce students to the environmental engineering discipline and related career opportunities. Discussions were held with students, alumni, faculty, and the video production team to define the video's focus. Based on the comments received, trajectories of environmental engineering graduates were selected as the central theme. We identified four graduates of the Environmental Engineering program across different specialties to conduct recorded interviews. The participants were asked to describe their professional responsibilities, career trajectories, and how they rely on their environmental engineering preparation. The video is now shown to students during the course's initial lectures. Figure 2 shows a screenshot of the video.

Figure 2: Screenshot of introductory video showcasing environmental engineering graduates.

Course website: A new course website was developed to improve the organization of course materials and facilitate their delivery. The website was created with the Moodle open-source software. All course materials and announcements are now shared through the website. A clearly-organized and consistent structure was created to hold learning materials. In addition to improved user-friendliness and visuals (e.g. banners, images, graphics, icons), several features were arranged to simplify course management for instructors and TAs. These include an online discussion forum, auto-gradable quizzes, and automatic links to the Top Hat system used to record student attendance and in-class activities.

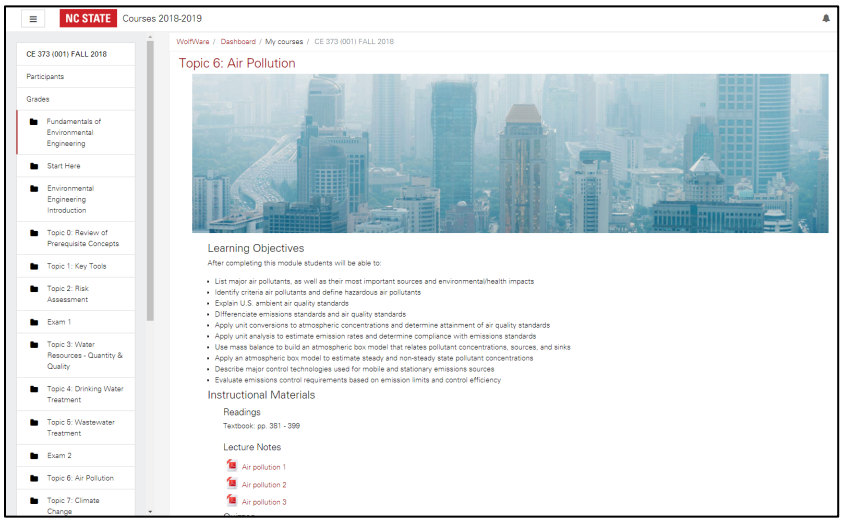

Figure 3: Screenshot of redesigned course website.

Top Hat implementation: Active learning has been identified as an effective method to improve student performance in engineering courses.4,5 The Top Hat teaching platform was implemented as a mechanism to foster and facilitate student engagement. Top Hat replaced the traditional clickers used in the course prior to the redesign. Through Top Hat, students' devices (e.g. cellular phones, laptop computers, or tablets) can be used to take launch questions and collect real-time responses. In the redesigned course, the tool is used to take attendance, complete in-class quizzes, and carry out live interactive polls. Questions were prepared with different formats, including multiple choice, short answer, matching, and ranking. Participation and grades are automatically recorded for all activities.

Assessment

Student survey data were collected before and after the redesign to assess student engagement and excitement. The post-redesign surveys were compared to the baseline survey in order to draw conclusions. An additional survey on Top Hat was included once the redesign was implemented. Important results from these surveys are summarized below.

Learning habits: One key finding was that students in the redesigned course self-reported higher levels of engagement in specific learning habits than their peers in the baseline sections. The redesign led to greater percentages of students reporting that they "often" and "every week" reread the current lecture notes, textbook chapters, or previous lecture notes.

Lectures: Regarding lectures in the redesign, roughly two-thirds (67.2%) of respondents agreed or strongly agreed that in-class lectures helped prepare them to complete HW assignments successfully. Sixty percent of respondents agreed or strongly agreed that 1) lectures were engaging and interesting, and 2) they helped provide a solid foundation to successfully complete course exams. The percentage of students that strongly agreed that the course materials were valuable aids to learning increased to 47%, up from 21% before the redesign.

Top Hat: The use of Top Hat was well received in the redesigned course. A majority (70.9%) agreed or strongly agreed that Top Hat is an effective way to add more interaction during lectures. Nearly half (47.3%) agreed or strongly agreed that Top Hat quizzes helped them see what they had learned, and where they needed to work on. In an open-ended question that asked students to provide a few aspects that were helpful for learning course material, there were five mentions of Top Hat out of 71 total responses for that question. They included "...Top Hat was engaging and provided concepts that were important for exam.", "The animations and top hat quizzes helped illustrate concepts and areas where I was struggling.", and "I really enjoyed the flipping of lecturers to bring different styles of teaching for different units. I also liked Top Hat and their quizzes/responses." These responses illustrate the effectiveness of Top Hat to engage students.

Homework: Student responses to HW-related survey questions were mixed. There were no significant differences (redesign vs. baseline) in respondents' 1) self-reported time spent on HW, 2) confidence in completing assignments correctly, and 3) belief that HW helped prepare them for exams. In the redesigned course, there was a significant increase in students feeling they needed help on HW relative to the baseline survey; however, significantly more respondents in the redesign survey reported actually getting help on HW. The redesign respondents also reported seeing more value in working with a partner on their HW.

Conclusions

The objective of the CE 373 course redesign was to increase student engagement and excitement about Environmental Engineering. Through creation of problem-solving visualization activities, web-based real-time interactions (via Top Hat), an updated course webpage, an introductory video, and reduction in the course scope, we fulfilled our objective across most of the course metrics (e.g., improving learning habits, engaging students during lectures). The implementation of new interactive technologies in the classroom was strongly supported by students. However, our assessment also shows that our redesign did not alleviate all challenges for the students, including the difficulties associated with homework assignments. Future efforts to determine how best to transfer engagement in the classroom to mastering problems outside the classroom are therefore needed.

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