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An Evaluation of a University-Level, High School Course Taught to Foster Interest in Civil Engineering (Evaluation)

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AN EVALUATION OF A UNIVERSITY-LEVEL, HIGH SCHOOL COURSE TAUGHT TO FOSTER INTEREST IN CIVIL ENGINEERING (EVALUATION)

ABSTRACT

High school students have limited exposure to engineering education, especially civil engineering. To fill this knowledge gap, the authors' offered a new college-level, civil engineering course to high school students. Initial course planning anticipated an on-campus environment with a focus on hands-on learning. Due to COVID-19 and the university system's response, the course shifted to an online platform. In this new setting, the course incorporated both synchronous and asynchronous modules with 18 students from geographical locations spanning 11 time zones. The students had diverse prior exposure to civil engineering, virtual learning environments, and active learning techniques. This paper evaluates the new program's effectiveness in increasing students' interest in civil engineering. Also, the paper shares detailed practical techniques that can be implemented to design (or redesign) courses intended to represent both a rigorous college class and foster interest in engineering. The effectiveness of this course is evaluated based on student engagement with online content, student evaluations, and comparison of pre- and post-class surveys. Student engagement was measured by class participation, on-time assignment submission, and time spent engaging with online materials. To get students' perspectives on course content, delivery method, and teaching techniques, class evaluations were administered to all students at the end of the course. Pre- and post-class surveys asked students uniform questions related to their definition of civil engineering, description of core class principles, and the university. The authors found that students appreciate group work, interactive activities, and opportunities to research and report on complex topics. Specific active learning techniques including split room debates, think-pair-share activities, and using novel software for real-time polling were mentioned by learners as especially meaningful. From the instructors' perspective, the success of these virtual interactive activities is predicated on learner buy-in. Initial ideas developed for in-person instruction were largely abandoned, and alternative approaches were used to leverage the assets and limit the drawbacks of an online environment. Some techniques used were issuing online polling solutions to encourage participation and putting learners in permanent groups to help combat feelings of isolation. Altogether, these techniques led learners to engage with civil engineering topics, fostering interest and growing their knowledge of the topic, while meeting the required rigor of the university classroom.

Introduction

High school students are increasingly interested in exploring engineering disciplines before college enrollment. These opportunities give students the ability to interact with engineering educators, understand the academic rigor, and meet peers in their area of interest. Students find these opportunities in traditional high school classes, after school programs, and summer programs held at colleges and universities. The authors recently started one such program for students interested in civil engineering. They entered this field because of a perceived need for civil engineering pre-college education and the proven effectiveness of summer programs in increasing student interest in STEM fields.

According to the U.S. Bureau of Labor Statistics [1], the domestic engineering field is anticipated to add over 130,000 jobs from 2016-2026. The largest portion of these jobs is for civil engineers who account for nearly a quarter of this anticipated job growth [1]. Despite the growing demand for civil engineering services, civil engineering enrollment in 2016-2017 dropped by approximately 3,000 students compared to 2008-2009 [2], [3]. This drop in civil engineering enrollment holds even though overall enrollment in engineering fields grew by nearly 200,000 during that same time frame [2], [3]. Together, these statistics suggest that more students are finding the field of engineering than ever before but are not interested in pursuing opportunities in civil engineering despite the anticipated industry need. The authors postulate that fostering interest in the field of civil engineering through a longer-term engagement with college-level civil engineering curriculum would begin addressing this need.

Colleges and universities across the U.S. have proven the viability of STEM courses taught at the college level for high school students. A University of Alabama program showed students retained knowledge learned in their programs, especially through interactive lab activities [4]. Another program geared towards electrical engineering found an increase in both student knowledge on the subject matter and interest in future studies in engineering and science fields [5]. Engineering career aspirations were also shown to increase in a Texas A&M summer program [6]. Another program found students showed great interest in studying engineering and engineering-related fields after their summer program [7]. Numerous additional studies echo the findings of this limited selection of studies [8-11]. Together, these studies show the potential of college-level courses for high school students to grow student knowledge, subject matter interest, career aspirations, and future college enrollment in STEM fields. When coupled with the documented need for civil engineering professionals, and declining national enrollment in civil engineering programs, the proven effectiveness of college and university level STEM programs for high school students suggests offering a university program for high school students could potentially grow an interest in civil engineering. The authors hoped that the findings from these studies could be translated to their civil engineering course at their institution.

In addition to the viability of the course, the authors also established the viability of a course at their home institution. The name and rank of the university suggest that the academic credentials are appropriate however, an additional consideration included logistical support within the university. Purdue had recently started a program specifically aimed at providing high school students an opportunity to come to campus for a one week, one-credit course where the university will provide assistance with logistics such as applications, housing, student supervision, and evening activities.

Program Implementation

The course, titled "Resiliency and Sustainability: Not Just Buzzwords", intended to provide students with a multi-disciplinary civil engineering understanding of these terms often used in discussions and policy conversations but less often understood in civil engineering contexts. The course was envisioned as a residential, one-week, one-credit offering under the umbrella of Purdue's Think Summer Program for High School Students. The course was open for rising high school juniors and seniors. This class was designed to have approximately six hours a day of student-instructor facetime over the five-day week. This instructional time included traditional lectures as well as field trips, laboratory experiments, and active learning activities. The home base for the course was an active learning classroom with features such as pod seating, movable tables, and whiteboards. Additionally, the intention was for students to visit various campus locations, view and participate in laboratory experiments, and learn more about the life of a residential student.

Initially, the course development focused on understanding the student population of the class; high school students have different background experiences than the college sophomores that the civil engineering school usually admits. The teaching team determined that limited assumptions could be made on the background knowledge of students as rising juniors and seniors would likely have different math and science backgrounds as no specific previous courses were required for students to be admitted to the program. Based on the student's demographics, namely high school juniors and seniors interested in an engineering course, the teaching team made general assumptions on their minimum math and science backgrounds. Namely, that students were proficient in algebra and middle school life sciences with no expectations that students had taken high school level geometry, statistics, physics, chemistry, or biology classes. Therefore, the course was designed to rely minimally on background knowledge and instead present students with the necessary perspectives to understand the materials provided to the class. As far as learning techniques, the teaching team assumed that students had significant interaction in high school classes suggesting that active learning techniques would be especially important to keep this demographic interested and engaged.

The course specifically covered the civil engineering specializations of transportation, hydrology (water), and structures as they relate to resiliency and sustainability discussions. Due to the limitations of a one-week course, the instructor team focused the course content on developing student depth in resiliency and sustainability topics in these areas of civil engineering instead of promoting a broad breadth of knowledge. The transportation section of the course focused on how connected and autonomous vehicles could contribute of resiliency and sustainability. The water portion of the course relied on having the students understand hydrological concerns through interacting with case studies of lakes around the world. The structures portion of the course introduced students to resiliency and sustainability issues in structural engineering and then asked students to research solutions to these perceived problems. Ultimately, the instructor team tasked students to integrate these concepts into a weeklong multidisciplinary project. In groups of three, students were challenged to investigate the resiliency and sustainability concerns of a chosen city, suggest solutions to these problems, and evaluate the effectiveness and feasibility of these solutions. This project was chosen because cities represent a clear intersection of civil engineering disciplines and the teaching team wanted this integration to help students see the inherent connection of distinct civil engineering disciplines. The instructor team provided a list of U.S. cities for groups to choose from. These cities all had publicly available resiliency and sustainability reports. This choice was made so that students spent the majority of their project time researching and brainstorming civil engineering solutions to resiliency and sustainability concerns rather than defining the scope of the problem. The project was also designed to promote student autonomy and interest by allowing the groups to both select the city and then creatively approach solving the city's problems that interested them the most.

The course development process was significantly affected in March 2020 due to COVID-19 and the university system's response to the developing pandemic. By mid-May, the instructor team was informed that this summer course would be offered exclusively online. Course components like laboratory experiments, field trips, and campus tours needed to be abandoned or rethought. Additionally, real-time instruction schedules would need to be limited as the final course enrollment was 18 students spanning 11 time zones. Based on this class make-up, the instructor team determined 11 am-2 pm ET was the only reasonable time block that the entire class could be expected to be engaged. This time block represented a 50% reduction in the student-instructor facetime initially anticipated for the class. To supplement this time, both asynchronous content and office hours at various time frames were developed. The instructor team desired for synchronous and asynchronous time to be used as effectively as possible. To accomplish this, course content that was going to be presented lecture style was pre-recorded and uploaded for students to watch asynchronously while synchronous sessions focused on active learning activities and group work. Students were broken up into 3 cohorts for most synchronous work and rotated through water, transportation, and structures lessons. The student cohorts were created to facilitate effective synchronous discussions and increase the quality of student-instructor facetime even if the quantity was diminished. In addition to these separate sections, at the beginning of each day, all students and instructors attended a 15-minute opening session with daily announcements, a short tour or live experiment in one of Purdue's civil engineering labs, and a short introduction to a notable campus location. These sessions were added to ensure that students understood the daily logistics and to bring as much of the Purdue residential experience as possible to the students.

The synchronous sessions incorporated many active learning techniques. These techniques were selected specifically because of their viability in online formats and the instructors' desire to focus on student engagement in the synchronous sessions. Selected activities included group work in breakout rooms, 3-2-1 activities, and a split room debate.

Group work in breakout rooms employed accessible tools allowing students to collaborate in real time including virtual white boards and Google docs. Students were given open-ended prompts to problems and asked to compare and contrast viable alternatives together on a virtual whiteboard. Instructors asked students to propose solutions to complex problems where individuals investigated one or two solutions and reported back to their group using shared Google docs.

In the 3-2-1 activity, students used the material from the asynchronous sessions to develop a presentation to share with their class that included: three things they learned, two thing they found particularly interesting, and one question they had about the lecture content. Students' questions were then assigned to their peers to answer as a homework assignment.

In the split room debate activity, students were asked about their stance on connected and automated vehicles: do the benefits outweigh the costs? In this activity, the instructor played a neutral role as a moderator shifting from one group to another to ensure all students had enough time to share their rationale behind their final standing.

For asynchronous content, the instructor team looked into multiple options for pre-recording videos. Ultimately, a system developed by Purdue capable of recording high-quality videos with limited required video editing was selected due to ease of use and accessibility during COVID. Several videos were also recorded via Zoom so students could see what project deliverables would look like in the same format that their teams would be using. In addition to these sessions, the Project teams were also required to check-in to office hours once a day to ensure that teams were making adequate progress and so that they had dedicated time to ask project-related questions. These choices lead to the sample daily schedule detailed in Table 1.

Table 1. Sample Daily Schedule

Time	**Event**		
9:00 am	Office Hours		
11:00 am	Opening Session		
11:15 am	Transportation Cohort 1	Water Cohort 2	Structures Cohort 3
12:15 pm	Transportation Cohort 2	Water Cohort 3	Structures Cohort 1
1:15 pm	Transportation Cohort 3	Water Cohort 1	Structures Cohort 2
3:00 pm	Office Hours		
4:00 pm	Office Hours		
At student discretion	Asynchronous lecture videos, homework assignments, and group project work		

After establishing the synchronous and asynchronous delivery, the instructor team explored different platforms for synchronous sessions. The perfect platform would be freely accessible for students, easy to use for instructors, incorporate useful features like breakout rooms, allow students to connect via telephone if necessary, and require minimal internet bandwidth. The team selected Zoom based on personal experience and professional recommendations. The platform features breakout rooms, polls, raising hand features, and virtual whiteboards. These features were used throughout synchronous sessions to facilitate engagement. In addition to these native features to Zoom, additional online tools such as live polling software, novel online timers, and Google docs were used to increase collaboration.

An online learning management system, in this case Brightspace, was employed to host content and post daily schedules and expectations. The instructor team anticipated communicating clear expectations would be difficult during the short duration of the course and without in-person instruction. Nevertheless, students clearly understanding expectations and being able to meet these expectations with course materials and support as necessary was critically important. Given that this audience was likely less familiar with learning management systems, the instructor team referred to all daily assignments in the live sessions as well as in the asynchronous videos, as appropriate. A breakdown of these daily activities is presented in Table 2.

Table 2. Daily Events

Monday	Tuesday	Wednesday	Thursday	Friday
• Introductions and expectations • Get to know each other game • Assign teams • Walkthrough learning management systems • What is civil engineering? • Resiliency and sustainability: why here, why now? • Introduce and discuss the project	• Welcome back and a quick shot of campus • Comparing and contrasting resiliency and sustainability in civil engineering • Introducing and identifying the resiliency and sustainability benefits of connected and automated vehicles. • Introduction to preliminary concepts of hydrology: hydrologic cycle, infiltration, rainfall etc.	• Welcome back and a quick shot of campus • Evaluating the resiliency and sustainability of a structure • Structures Lab Video Tour • Identifying the potential challenges for the deployment of connected and automated vehicles. • Principle of mass balance in hydrology • Impacts of climate change on sustainability and resiliency of water resources	• Welcome back and a quick shot of campus • How could we improve building codes to address resiliency and sustainability more? • What is your standing on connected and automated vehicles: do the benefits outweigh the costs? • Feedback mechanisms and their role in resiliency of ecosystems	• Welcome back and a quick shot of campus • Information session from the admissions office and first-year engineering program • Project presentations in groups and questions • Class closing session

Program Evaluation

Program evaluation focused on three main data sources: student engagement with materials, initial and final survey comparisons, and course evaluation results. In addition to these components, anecdotal experiences of instructors also serve to inform future designers of similar classes of items to emphasize and avoid.

Student engagement was measured by the number of students that engaged with course materials. Due to the nature of an online class, this was measured by how many students completed the assignments and, also, how many of these were completed on time. Four categories of assignments were evaluated: Homework, Quizzes, In-class Activity Writeups, and Videos. Figure 1 presents the engagement with these different categories. Nearly all students watched all the course videos and completed all quizzes. However, homework and in-class activity write-ups were less likely to be turned in. Moreover, quizzes were the most likely to be submitted late although nearly all quizzes were turned in eventually. Authors postulate that the videos and quizzes show the highest level of engagement because they required the least amount of active engagement with course content. Students need only hit play to engage with the videos and the quizzes were multiple choice questions based on the videos. Given the limited number of assignments (as the course was only 5 days long), a surprising number of assignments were not turned in at all. These missing assignments then had a large impact on students' overall grades – unsurprisingly, the students with the lowest grades failed to submit multiple assignments. Instructors made an extra effort to email students with outstanding assignments but many of these assignments were still not completed. One of the reasons for the missed assignments, as one of students pointed out in anonymous feedback, was that students simply did not have enough time to understand the material and complete the assignments.

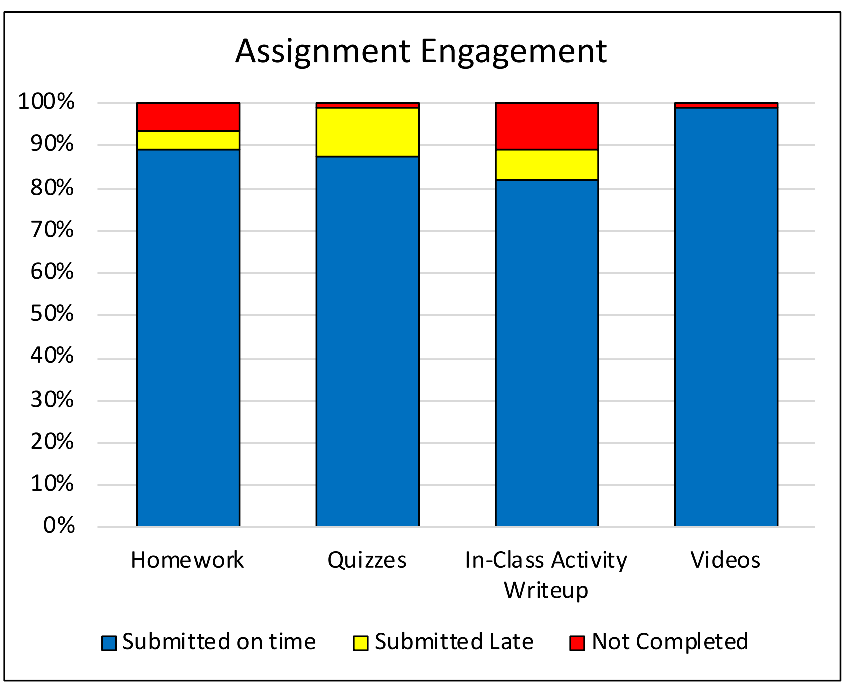


Figure 1. Student engagement on assignments.

The course was also evaluated based on initial and final surveys taken by the students. These surveys each contained the same questions: (1) How would you define civil engineering?; (2) How would you describe resiliency?; (3) How would you describe sustainability? These surveys were administered through the online learning management system and unproctored. Students were told that they would not be graded on their answers, just on their completion, and that the instructors were not looking for the 'correct' answer but rather their initial thoughts (and not Google's thoughts). Through asking these questions, the instructors hoped to see if students' understanding of civil engineering, resiliency, and sustainability changed through their experience. Typical results from these surveys are shown in Table 3. From an initial comparison, it is evident that student responses were longer and used more language relating to resiliency and sustainability at the end of the course.

Table 3. Typical pre- and post-program responses to survey questions.

Pre-program Responses	**Post-program Responses**
How would you define civil engineering?	
Designing and maintaining civil structures.	Civil engineering is the field of engineering devoted to making technology and systems more sustainable in their everyday function, and more resilient in the face of a major threat.
The field of engineering that works on infrastructure.	I would define civil engineering as design, construction, and maintenance of a structure or system that is resilient and sustainable to the environment.
Civil engineering is the study of infrastructure and how it works.	Civil engineering is the science behind creating resilient and sustainable structures that are used in everyday life.
Designing and overseeing the construction of structures.	Civil engineering is the engineering discipline responsible for dealing with the sustainability and resiliency of different aspects of infrastructure.
How would you describe resiliency?	
The ability to not be shaken by obstacles or struggles.	Resiliency is the ability of a system to absorb/minimize the damage of a threat or hazard, to maintain some degree of functionality, and to recover from it.
Resiliency is something's ability to function after it has been damaged.	Resiliency is a system's ability to absorb the shock of damaging events as well as how quickly it is then able to recover.
Resiliency is sort of like the ability to withstand problems.	Resilience is the ability for something to absorb a shock and recover quickly.

How would you describe sustainability?	
How long something is able to work effectively.	Sustainability is the ability for something to resist devastating change and promote a healthy environment.
A prospect of life that is renewable for you.	Sustainability is the process of limiting energy usage, limiting CO2 emissions, and how something effects its community.
Being able to work over a long period of time.	The ability of a system to be long-lasting as well as being efficient and environmentally friendly.

Common student response to question 1 are quantified in Figure 2. In initial surveys, most of the students recognized civil engineering as a field that deals with structures as indicated by words like buildings, structures, and infrastructure. In the final survey, students had a greater diversity of words to describe the field. Buildings, structures, and infrastructure still appeared but course buzzwords – resilient and sustainable – also appeared very frequently. These results suggest that the students took away the importance of resiliency and sustainably in civil engineering. This increase in vocabulary is also evident in the sample responses in Table 3.

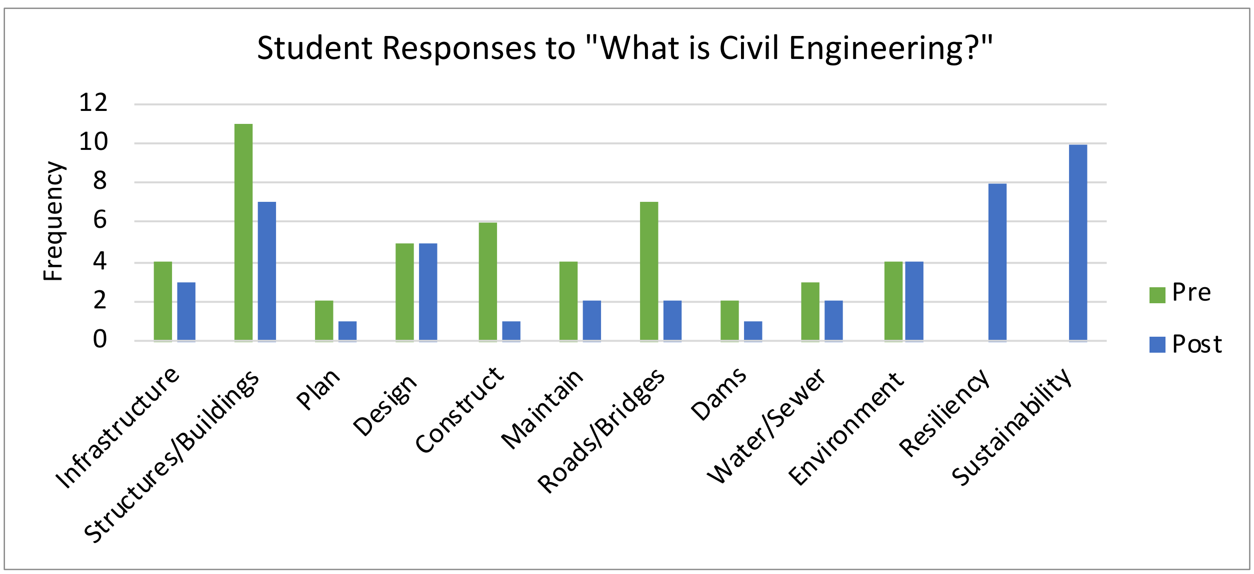


Figure 2. Student responses to question 1: How would you define civil engineering?

As seen in Figure 3, student definitions of resiliency focused on similar words at the beginning and the end of the course like disaster, withstand, and recover. More than redefining resiliency, students appear to have developed a larger vocabulary to discuss resiliency with words such as absorb, hazard, and adversity appearing in final survey results. These words may build on their earlier understanding of structures ability to withstand, recover, and bounce back.

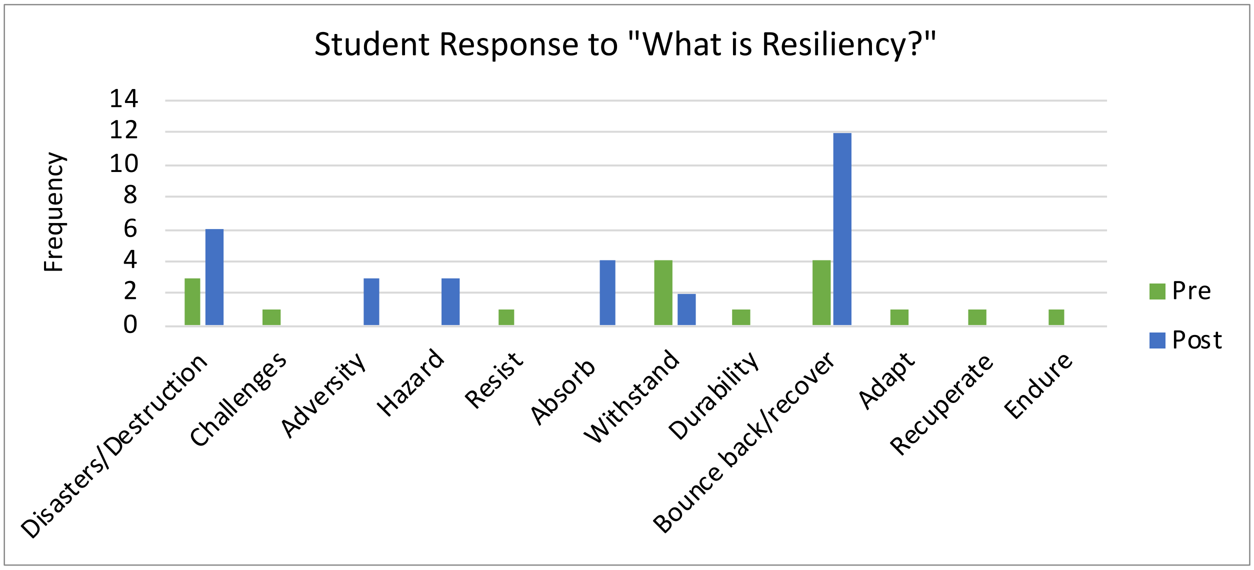


Figure 3. Student responses question 2: How would you describe resiliency?

Figure 4 details the student responses related to sustainability. Before taking the class, most of the students described sustainability with phrases like "long time" or "long period." Combining the most popular responses yields a community definition similar to: the ability to maintain something over a long of time. Although these components still appear in later answers, other words jump in popularity such as efficiency, environment, and energy. This suggests that students have amended their definitions to more frequently connect sustainability and civil engineering applications. These responses suggest students had a more comprehensive understanding of sustainability after taking the class, recognizing the environmental aspect of the sustainability discussion.

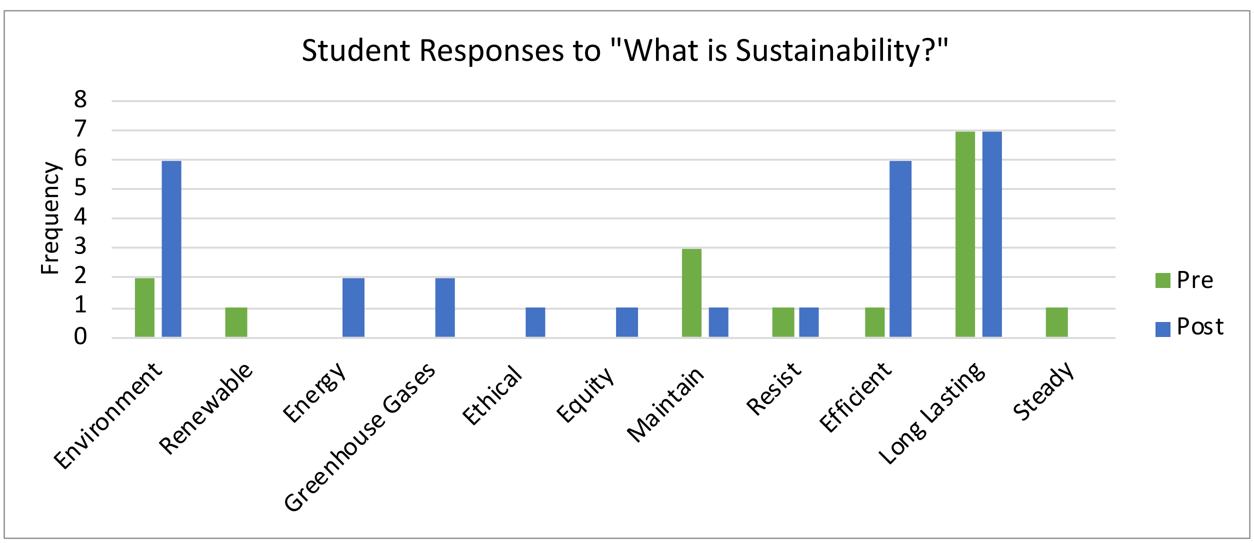
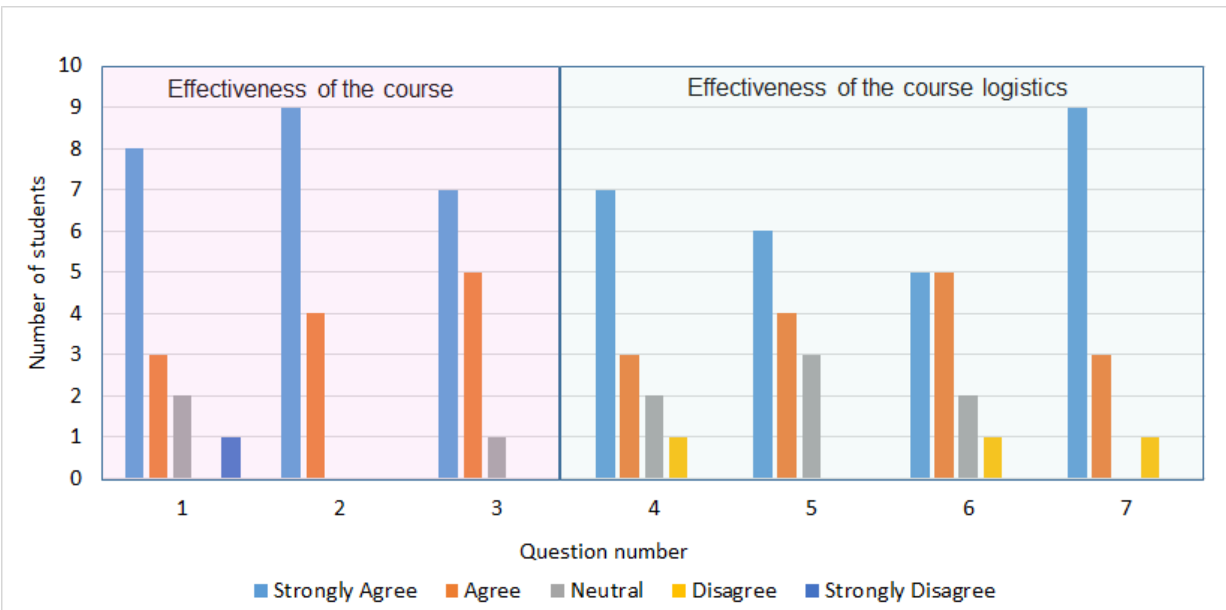


Figure 4. Student responses to question 3: How would you describe sustainability?

Overall, the survey responses left an imperfect picture of student growth over the week. Students expressed a greater understanding of the breadth of civil engineering and the connection between sustainability and environmental impact, but limited notable difference was observed in the definitions of resiliency or sustainability. The instructors suspect that some of this ambiguity is likely from the format that the survey results were collected. For example, the students had access to the internet and therefore some initial responses resembled the top Google hits. Other students answered nearly identical on initial and final surveys as they had access to their initial responses when completing the final evaluation.

Finally, an anonymous student feedback survey was administered to specifically evaluate course content, teaching methods, and perceived learning (Figure 5). The survey was completed by 13 out of the 18 students. Across the topics covered, students had largely positive feedback. Twelve students agreed that the subject matter increased their knowledge and 10 students agreed that the teaching methods used were helpful. Eleven students agreed that the course had increased their interest in civil engineering. When asked about their favorite part of the course, most students mentioned the final team-project, working with their peers, and the transportation split room debate activity. Students suggest the course could be improved by decreasing the amount of asynchronous work, more clearly presenting expectations, and increasing connections between the different disciplines of civil engineering discussed.



Questions: (1) This class has increased my interest in this field of study; (2) This course broadened my knowledge of the study and practice of civil engineering; (3) The instructional materials (i.e., video lectures, readings, handouts, etc.) increased my knowledge and skills in the subject matter (4) The course was organized in a manner that helped me understand underlying concepts; (5) The lectures, readings, and assignments complemented each other; (6) Expectations for student learning were clearly defined; (7) I believe that what I am being asked to learn in this course is important.

Figure 5. Students' response to anonymous feedback survey

In addition to this measurable feedback, the instructor team also learned from anecdotal experiences. Students were easily overwhelmed, especially initially – breaking in-class activities, assignments, and the project into small pieces helped reduce this hurdle. The instructor team needed to be very organized when presenting content together lest instructors accidentally talk over, interrupt, or neglect something. To avoid this issue, detailed lesson plans were developed for a session involving multiple instructors. Simple things like who was in charge of the technical Zoom components, who was taking attendance, and who was dismissing students at the end of the session were all included in the lesson plan. Students also needed frequent reminders on expectations, assignments, and where to go when. Daily opening sessions were helpful to provide these reminders, answer student questions, and solve any technical issues early.

Activities selected for the synchronous sessions were especially proven effective when they were more student led, such as the split room debate activity. In one case, the instructor lost connection to the synchronous session due to technical difficulties. At the time, the students were in the midst of their split room debate activity and continued their way through the debate session even during a period when the instructor was unable to join. The effectiveness of this session was echoed in the students' feedback survey in which this activity was often mentioned as their favorite.

Conclusions

Civil engineering education is vital to meeting industry demands in the coming years. This course sought to foster an interest in civil engineering in potential engineering students of tomorrow – high school students. Although initially developed as a hands-on residential experience, the course was redesigned for virtual delivery due to COVID-19. Consequentially, active learning techniques including 3-2-1 activities, split room debates, and group work in breakout rooms were employed through interactive Zoom sessions. Ultimately, students left the course with a greater understanding of civil engineering, new definitions of resiliency and sustainability, and college experience.

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