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Teaching the First-Year, Hands-On Engineering Design Experience Online

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Teaching the First-Year, Hands-On Engineering Design Experience Online

Abstract

During the summer of 2020, a team of faculty reimagined the School of Engineering's first-year design course to increase consistency among sections, to create space for first-year students attending online classes to form friendships, to explicitly teach design thinking and problem solving in a virtual environment, and to integrate ethics into the project-based course. This fall-term course enrolled the first-year class of approximately 140 chemical, civil, electrical, mechanical, and general engineering students. Interdisciplinary teams worked on projects in the general theme of "Engineering for Social Good." Project topics included: designing smarter and more resilient cities, developing therapeutic devices, designing shelter for refugees in flight, and making fuel from food waste. The faculty designed and led their own section's projects while having a set of common activities and deliverables with similar timelines and baseline rubrics. To build community among the students, every project team had a maximum of eight students with an assigned undergraduate teaching assistant. Each class dealt with the limits of the pandemic in different ways. For instance, some courses developed "@Home" kits, some courses provided limited access to campus spaces, and some courses had all virtual projects. The faculty met weekly to assess course progress. Additionally, a survey was developed to assess students' learning gains, their experiences in the course, and approaches to handling a project-based course in the era of COVID.

Introduction

In the summer of 2020, a group of faculty teaching the Cooper Union's first-year engineering design course (Engineering Design and Problem Solving – EID101) conducted a course assessment and redesign, which included adjustments to transition the course to a primarily virtual environment for the Fall 2020 semester. The first-year design course has been running as a project-based learning (PBL) course for the past several years. The course is part of a growing trend for first-year engineering curricula to include team-based, experiential engineering courses [1–3] and to give students space for bonding and risk-taking.

The benefits of PBL courses include improvements in retention, engagement, student motivation, critical thinking, and relationship building [1, 4]. The faculty wanted to retain the PBL nature of the course and many of the associated objectives while incorporating aspects of participatory design. The incorporation of participatory design (PD), facilitated by the teaching team's attendance at the 2020 Olin Summer Institute, teaches students to view design as a collaborative effort with each other and the users or communities for which they are designing solutions [5, 6]. Thus, faculty in the redesigned course focused on having students learn and work on problem formation in addition to problem solving. The intent was, through PD, students and faculty would develop a deeper understanding of context during the problem formation process.

The contribution of this work is a redesign and assessment of a PBL design course that was run in the virtual environment because of the COVID-19 pandemic. Under these circumstances,

several modifications were made for the Fall 2020 semester, including hiring teaching assistants (TAs), increasing the amount of shared content between different course sections (that could be easily facilitated on Zoom), and allowing final projects to be either physically-built or virtual (e.g. software, websites, or phone applications). These modifications were designed to fulfill the learning objectives of the course and encourage students to develop teamwork skills and establish relationships with their peers. An end-of-semester survey was administered to assess the gains that the students made in their understanding of the course objectives, the impact of the TAs in the classroom, and how well the students communicated and formed friendships.

Background

EID101 is a project-based course that was designed to introduce students to hands-on, team-based engineering projects and to university facilities, such as the machine shop and the library. Traditionally, five-to-seven sections of the course were run each Fall semester by faculty members from different engineering departments. The shared components of the course were an introductory lecture, midterm and final presentations of the students' projects, and a patent workshop. Visits from staff of the University's library, writing center, and machine shop were coordinated within each section. The course had a shared general syllabus with a set of learning objectives including teaching students how to work in teams, communicate effectively, use simple tools, and develop critical thinking skills.

The faculty redesigned the course during the summer of 2020 with help from the Olin Summer Institute, to create a co-taught course with more shared content and organization and an updated set of learning objectives. The redesign included considering the course in the larger context of the curriculum and, in particular, the current first-year experience. Although the redesign was planned prior to the COVID-19 pandemic, additional considerations were made to transition the course to the virtual environment, especially considering that effective online teaching requires additional skills and pedagogy compared to in-person teaching [7, 8].

Issues that the faculty were interested in addressing were: finding mechanisms for how to sustain some student projects within the curriculum; creating a shared ethics curriculum and assignment; incorporating concepts of participatory design; developing skills in giving critical feedback; and incorporating inclusive teaching practices. The updated course learning objectives for the Fall 2020 semester are given below:

1. Students will be able to identify steps of the design process and use the design process to form problem statements
2. Students will be able to create, articulate, and use a methodology to evaluate design solutions
3. Students will be able to work within a team and create methods to manage and organize team activities
4. Students will be able to construct and deliver critical feedback for their peers and incorporate feedback into their designs
5. Students will be able to describe the components of good technical writing and oral communication and evaluate these aspects in their own writing and presentations.

6. Students will be able to identify and develop necessary tools to solve problems
7. Students will develop an awareness and appreciation for the societal, legal, ethical and environmental responsibilities of engineering

The team designed a co-teaching model with designated weekly meeting time to align content and plan shared classes. A set of shared "workshops" were outlined by faculty during the Olin Summer Institute and designed by the faculty during the semester. The list of shared workshops that were run are shown in Table 1.

Table 1: Shared course workshops developed for the Fall 2020 semester

Full Course Workshops	Delivery	Content	Learning Objectives
Course Introduction	Synchronous, Via Zoom	Overview of each section's themes and guidelines for classroom discussions	1, 6
Participatory Design Workshop	Synchronous, Via Zoom	Workshop for students to learn the stages of the design process and identify a problem by listening to people's interests, concerns, and needs	1, 2, 3
Ethics Workshop	Synchronous, Via Zoom	Ethics workshop which included a case study and small-group power mapping activity.	7
Midterm Presentation & Feedback Session	Synchronous, mixed section groups	Midterm session with student peer review and discussion of project proposals across sessions.	4
Writing workshop	Asynchronous videos	Video on the writing rubric and how to evaluate writing for clarity, economy, and precision. Video on how to properly cite scientific research.	5
Oral communication workshop	Asynchronous videos	Videos on how to create good presentation visuals and develop a presentation storyline	5

The shared workshops were designed to be delivered synchronously with all students in a single Zoom meeting or as videos that individual instructors could use within their own lessons. The shared workshops made up a small fraction of lessons (12%) and the remaining lessons were designed and delivered by individual instructors within their sections. Asynchronous videos were chosen to cover content that required less student involvement or activities and for content that was less likely to change in future semesters. Videos on how to write technical research papers, ranging from two to six minutes, were made in conjunction with the University Writing Center. The videos covered topics on how to cite scientific research and how to use the research paper rubric to evaluate their work. Similarly, videos were made by the instructors on how to develop effective presentations and included hands-on activities for the students to complete individually

or with their teams. All of the technical communication videos were used by individual instructors as they saw fit. Visits from the University librarians were scheduled within individual sections and with individual instructors and are not shown in Table 1.

In addition to shared content for workshops, there were six shared assignments that were designed by the teaching team (shown in Table 2). Common descriptions and rubrics were created for the research project, the midterm, and the final project. A shared midterm presentation experience was designed and coordinated in Zoom so that each student delivered a "pitch" of their project to students from other sections and groups. Guidance on how students should give feedback was discussed and built into a template for the session. Peer review was also integrated into the background research assignment. While a shared background research assignment had been administered by individual faculty in the past, the current assignment included a shared rubric for the peer-review and faculty-review. Methods for peer-to-peer review were discussed within the teaching team and each instructor used their own method for peer review.

Table 2: Shared course assignments for the Fall 2020 semester

Shared Assignments:	Learning Objectives:	Shared Rubric:
Background Research Paper	4, 5	Yes
Midterm Presentation "Pitch"	3, 4, 5	Yes
Ethics Reading/Reflection	7	No
Participatory Design: Problem identification	1, 3	Yes
Participatory Design: Decision Matrix	2, 3,6	No
Final 5-min video presentation	3, 5	No

Fall 2020 Course Specifics

In the Fall of 2020, 139 first-year and transfer students registered for EID101. The percentage of students in each major was 16% in Chemical Engineering, 28% in Civil Engineering, 19% in Electrical Engineering, 25% in Mechanical Engineering, and 11% in General Engineering. Each of the six sections had between 22-25 students and consisted of students from each major. Under the general theme of "Engineering for Social Good," each section focused on a different topic: Smart Cities, Re-envisioning Waste, Critical Infrastructure Resilience, Rehabilitation Therapeutic Devices, Social and Ecological Resilience through Food, and Refugee-in-Flight Shelter Kits.

In previous semesters of the course, one of the common elements across sections was a physically-built component, whereas, in the Fall 2020, there were projects that consisted of non-physical products, such as websites and phone applications. The inclusion of physically-built components in Fall 2020 was at the discretion of each individual section's instructor. While some sections chose to have only physically-built or virtual final projects, others had hybrid projects in which group members divided work on physically-built and virtual components. For

projects with physically-built components, materials were either shipped to students or partially constructed on-campus. Further, in one section, a technology and design kit was shipped to students to introduce them to fundamental programing, microcontrollers, design, and prototyping skills regardless of their group project's needs.

For the Fall 2020, three teaching assistants (2^{nd}-4^{th} year students) were hired for each section, and one was assigned to each project group. The teaching assistants (TAs) were added to the course recognizing that students might face challenges with team bonding, and that faculty could face new challenges with purchasing, preparing, and shipping materials. Each instructor gave the teaching assistants different responsibilities that were appropriate for their sections. Two of the six sections assigned primarily administrative duties, such as budget management, to the teaching assistants. The TAs in the remaining sections had group mentoring responsibilities, such as facilitating in-class activities, managing group discussions and dynamics, and guiding technical content, to help enhance and reinforce the course learning objectives [9].

End-of-Semester Survey

Survey Questions/Explanation

The instructors created an end-of-semester survey to evaluate student experiences and the effectiveness of course features in the online environment. The students were first asked to answer general questions about their EID101 section, major, gender identity, and group project (e.g., whether or not their project had a built component, how often their group met outside of class hours, etc.). The main section of the survey was divided into five topics: communication, team bonding, impact of teaching assistants, gains in understanding the learning objectives (See Background/Course Description), and helpfulness of the course features (See Table 1) in achieving the learning objectives. The full survey is described in Table 3 and Table 4. The survey was prepared specifically for the Fall 2020 course, and thus, there was not a baseline comparison from previous semesters.

Table 3 lists the statements in three topics – communication, team bonding, and impact of teaching assistants – that students rated according to their experiences. In each section, students were given a set of statements and asked to rate each statement based on how relevant or true it was to their experiences in EID101. The five-point Likert scale ranged from -2 (Strongly Disagree) to +2 (Strongly Agree).

Table 3: Survey evaluation of student experiences related to communication, team bonding, and interaction with TAs

Topic	Statements
Communication	1. I feel that our group needed to communicate more often. 2. I feel that our group would have had better communication if we had been able to meet in person.

	3. I was able to express ideas and opinions during group meetings. 4. My groupmates were able to express their ideas and opinions during group meetings. 5. I feel that our group communicated well this semester.
Team Bonding	1. The groups in EID101 helped me to form friendships. 2. I got to know my groupmates this semester. 3. I feel that I formed lasting friendships/connections this semester. 4. I am comfortable being myself with my classmates. 5. My instructor encouraged us to bond and helped us form friendships.
Impact of Teaching Assistant Mentor	1. I feel comfortable asking my TAs for help/advice on my EID101 project. 2. I feel comfortable asking my TAs for help/advice on other problems outside of EID101.

Table 4 describes the latter two topics in the main section of the survey, in which students were asked to rate their gains in understanding the course objectives and the helpfulness of each of the course features in learning the course objectives. For gains in understanding course objectives, the five-point Likert scale ranged from 0 (No Gains) to 4 (Great Gain), and for helpfulness of course features, the scale ranged from 0 (Not at All Helpful) to 4 (Extremely Helpful).

Table 4: Survey evaluation of student gains in understanding and the helpfulness of course features in achieving gains

Topic	**Objective/Feature**
Gains in Understanding the Learning Objectives	1. Describing the steps of the design process 2. Forming a problem statement for a project 3. Working with a team to create methods to manage and organize team activities 4. Constructing and delivering feedback to my peers and incorporate feedback into my own work 5. Identifying a problem and the tools needed to solve it 6. Awareness and appreciation for the societal, legal, ethical, and environmental responsibility of engineers.
Helpfulness of Course Features in Achieving the Learning Objectives	1. Course Introduction: Inclusivity and classroom discussion guidelines 2. Participatory Design Workshop 3. Technical Writing Workshop

	4. Ethics Workshop 5. Oral Communication Workshop 6. Interacting with the instructor in/out of class 7. Interacting with the TAs in/out of class 8. Interacting with peers during class activities and/or homework

Students were also asked to choose their primary motivation for completing their course projects. The question asked the students to choose between their final grade, personal investment in the project, group dynamic, other, or none of the above. All of the students who selected "other" (six students total) indicated that all of the options (grade, personal investment, and group dynamic) contributed to their motivation; therefore, this group was renamed "all."

Lastly, the students were asked to respond to open-ended questions describing valuable aspects of the course and opportunities for improvement.

Analysis of variance (ANOVA) [10] was used to investigate the statistical differences in the responses for each Likert-scale question separately. A custom-built Python script was used to conduct the statistical analyses using the *statsmodels* module (https://www.statsmodels.org/). The factors in each general linear model (GLM) included whether or not the students had a physically-built component of their design, the role of the TA (Mentor or Administrative), and their indicated motivation, as well as the interactions between these treatments. If interaction terms were statistically insignificant, the model was re-run with the terms removed. For each final model, mean comparisons were drawn with a Tukey-Kramer adjustment.

The survey was delivered through Microsoft Forms. Ultimately, 99 out of 139 first-year students completed the survey. The breakdown of respondents according to major was 18% chemical, 26% civil, 19% electrical, 25% mechanical, and 11% general engineering, which was representative of the total make-up of the class. The breakdown according to gender identification was: 27% women, 69% men, 2% non-binary, and 2% preferred not to say.

Results

A major concern for teaching EID101 during COVID-19 was the effectiveness of a virtual "hands-on" engineering design course for teaching the design process and promoting student bonding. The primary reasons for conducting the end-of-semester survey were to understand how well students completed the learning objectives of the course and to evaluate overall student experiences. On average, the 99 students that submitted the survey said that they had good gains (rated scores ~3 out of 4) in each of the seven learning objectives. Additionally, 74% of students reported either somewhat or strongly agreeing (Likert-scale responses of +1 or +2) that working with their EID101 groups helped them to form friendships.

Effect of physically-built components on gains in learning objectives

Out of the 99 respondents, 64 students reported having a physically-built component to their final project, while 35 students did not have a built component (see Figure 1). Those with a physically-built component specified whether they built part of their project at home with self-bought materials (65%), built part of the project on campus (19%), or built part of the project with a @Home Kit that was mailed to them (16%).

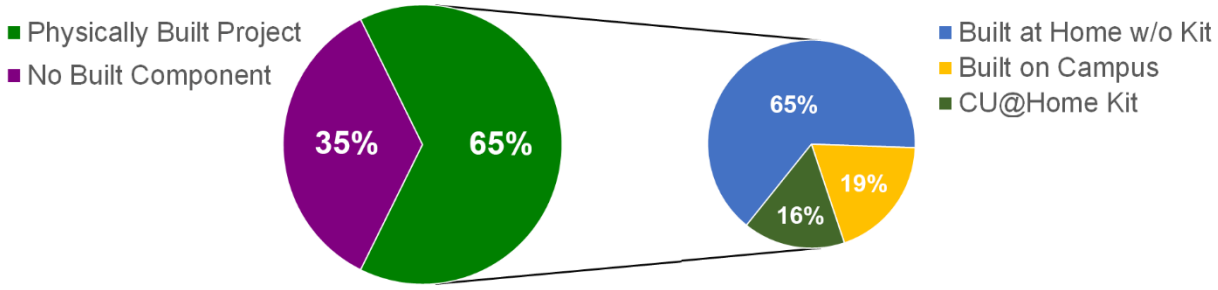

Figure 1: Class responses to the question: "Did your project have a physically built component?" (Total responses = 99)

Since past iterations of the course had focused primarily on physically-built components, an objective of the end-of-semester survey was to determine whether having a physically-built final project affected the student assessment of gains in each of the learning objectives. From the ANOVA, there was no significant effect ($p > 0.05$ for each objective) of having a physically-built component on the perceived learning objective gains (see Figure 2), which means that the students rated each objective similarly whether or not they had a physical component in their project. This result shows that the final projects that students complete do not need to be physical to accomplish learning objectives for a design-based course.

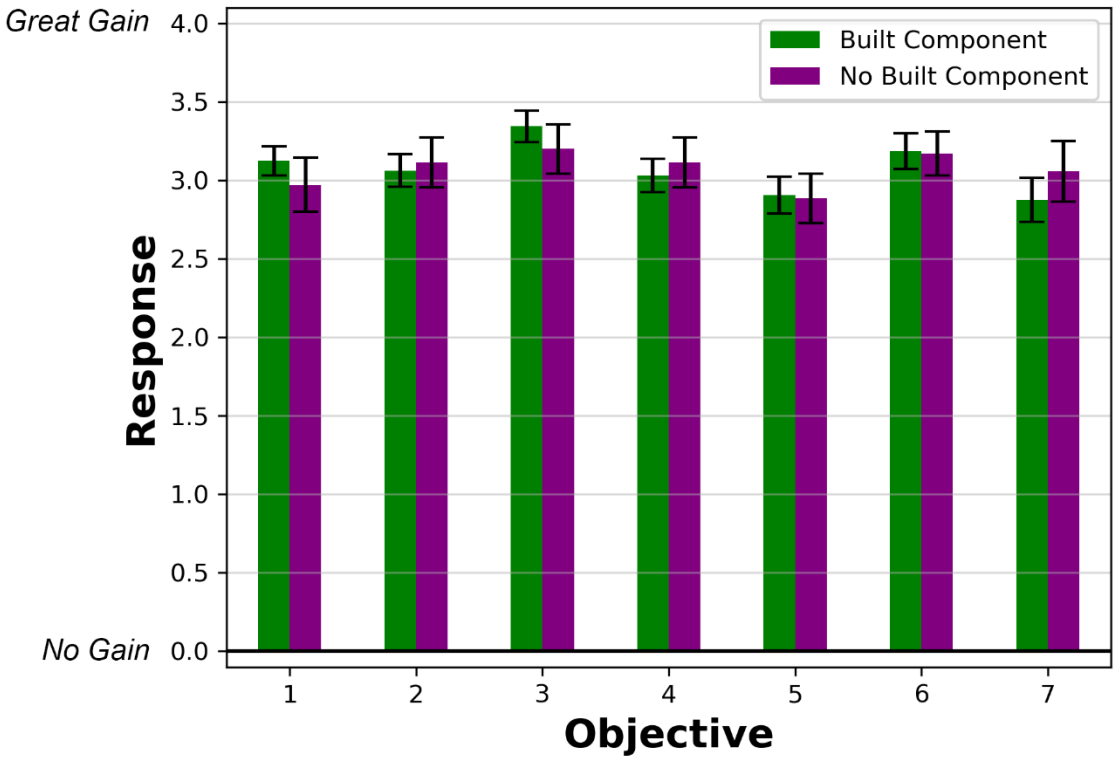

Figure 2: Gains in each learning objective by whether or not students participated in a project with a physical built component. Means are reported with standard error bars.

Effect of the role of the TA on learning objectives, communication, and bonding

Another added feature in the course's redesign is the assignment of undergraduate TAs for each EID101 section. The undergraduate TAs had different roles depending on section. In some sections, TAs primarily performed administrative tasks to help the faculty and students organize and execute their projects, while in the other sections, the TAs served primarily as student mentors to help guide the students with the technical content of their projects and connecting with each other in a virtual space. The students' perceived gains in learning objectives were compared based on the roles their TAs had in their section to evaluate the impact of those roles. From the ANOVA, TA role had a significant impact ($p = 0.03$) on only learning objective 5, which focused on students' written and oral communication skills, while the TA role did not significantly affect the students' learning gains in the remaining objectives ($p > 0.05$). As seen in Figure 3, students whose TAs were primarily mentors for their project groups reported higher gains in technical writing and oral communication. This result may have been because TAs that served as mentors spent time critiquing project reports and the midterm/final presentations.

Although TA role did not have significant impacts on most learning gains, it did impact how well student groups communicated. Students with TAs that served primarily as mentors

disagreed with the statement, “I feel that our group needed to communicate more often” with an average score of -0.5 whereas students with administrative TAs somewhat agreed with the statement with an average score of +0.2. These results are shown in Figures 3 below. Based on the ANOVA results, the effect of TA role on students’ response to this statement was statistically significant, with a p-value of 0.007. Similarly, students with TAs serving as mentors responded statistically higher to the statement, “My instructor encouraged us to bond and helped us form friendships” ($p = 0.01$; see Figure 4). Both groups of students responded positively to this statement on average. Although this statement focuses on the instructors’ contributions to encouraging bonding, and there was not a separate statement to record students’ perception of the TAs’ role in this goal. This data suggests that the TAs may have helped instructors facilitate peer bonding. The faculty view this as a positive outcome of including an assigned TA for each group.

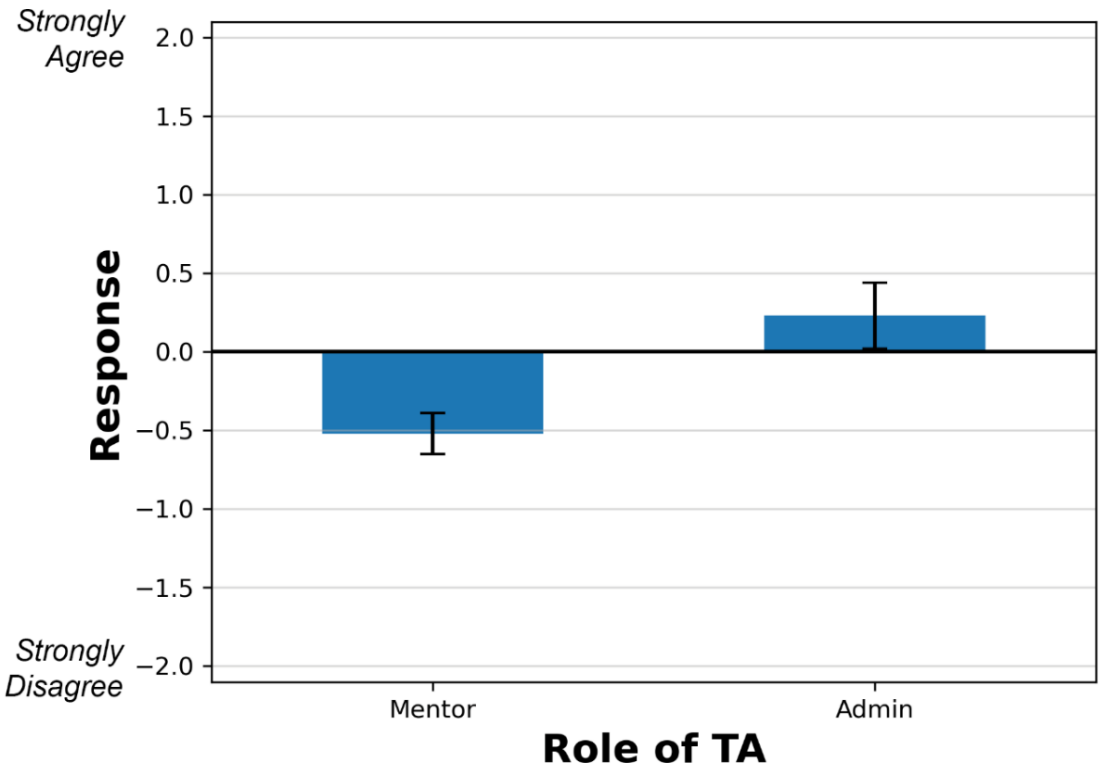

Figure 3: Student responses to “I feel our group needed to communicate more often,” which ranged from –2 (Strongly Disagree) to +2 (Strongly Agree) averaged over students that had TAs that took the role of a mentor compared to TAs that took an administrative role. The means, reported here with standard error bars, were significantly different with $p = 0.007$.

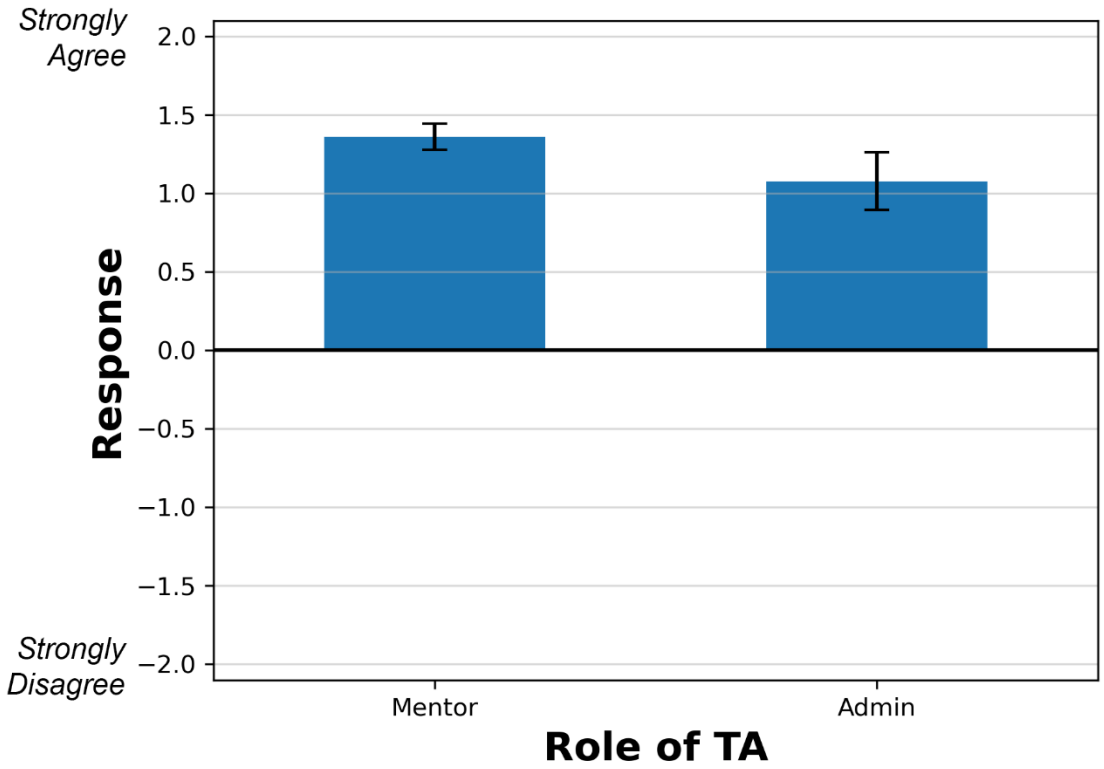

Figure 4: Student responses to "My instructor encouraged us to bond and helped us form friendships," which ranged from –2 (Strongly Disagree) to +2 (Strongly Agree) averaged over students that had TAs that took the role of a mentor compared to TAs that took an administrative role. The means, reported here with standard error bars, were significantly different with p = 0.01.

Student Motivation

Another unique aspect of the EID101 course in the Fall 2020, compared to previous iterations of the course, was the incorporation of the PD approach. The PD workshop (Table 1) and associated assignments (Table 2) were meant to guide students to develop problem statements rather than just respond to a given problem assignment. Thus, the faculty wanted to understand whether students felt strongly about their project topics. Additionally, the faculty wanted to know whether students that formed stronger bonds in the online environment felt more motivated or excited by their projects. Figure 5 shows student responses to the question "Which of the following motivated you the most to complete your project?" The results were surprising, in that so many students felt motivated by factors other than their final grades. Only 14% of student responders said that their final grade was the most motivating factor for their work in the course. Instead, the two primary motivating factors were the group dynamic (46%), and their personal investment in the project (31%). The separation of grade from motivation was remarked upon by

several students in open-ended responses about the course. As one student said "[the course is] less about the grade and more about the task at hand."

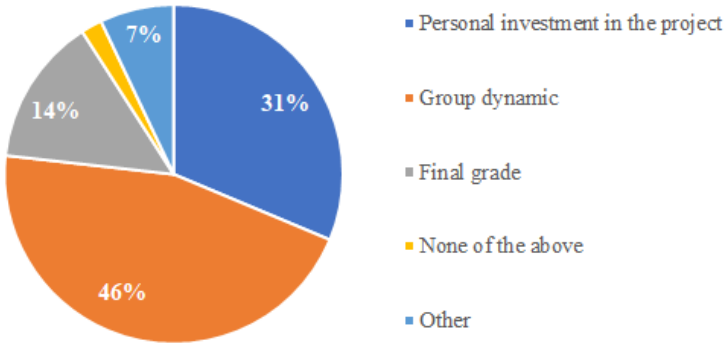

Figure 5: Student responses to the question: " Which of the following motivated you the most to complete your project?"

The ANOVA results indicated that student motivation in the course was a statistically significant factor in their responses to questions on communication and bonding. The results shown in Figure 6 demonstrate the statistical significance between how well students felt their group communicated and what they felt was the most motivating factor for their work in the course. Specifically, those motivated by group dynamics, largely disagreed with the statement that their group needed to communicate more often (Figure 7), whereas students without any reported motivation tended to agree with the statement ($p = 0.03$). Additionally, students that felt motivated by group dynamics responded positively to the question, "I got to know my groupmates this semester" while students that did not feel motivated by any of the offered options (i.e., "None of the above") reported statistically lower scores to the same question ($p = 0.048$; Figure 7). These results suggest that student motivation in the course is often driven by student connections and group dynamics. The results support the amount of time in the curriculum dedicated to teaching students how to work in groups and will reinforce this in future iterations of the curriculum. Another outcome of these results is that faculty will hold a training session for teaching assistant for the Fall 2021 to prepare them to mentor and support student groups.

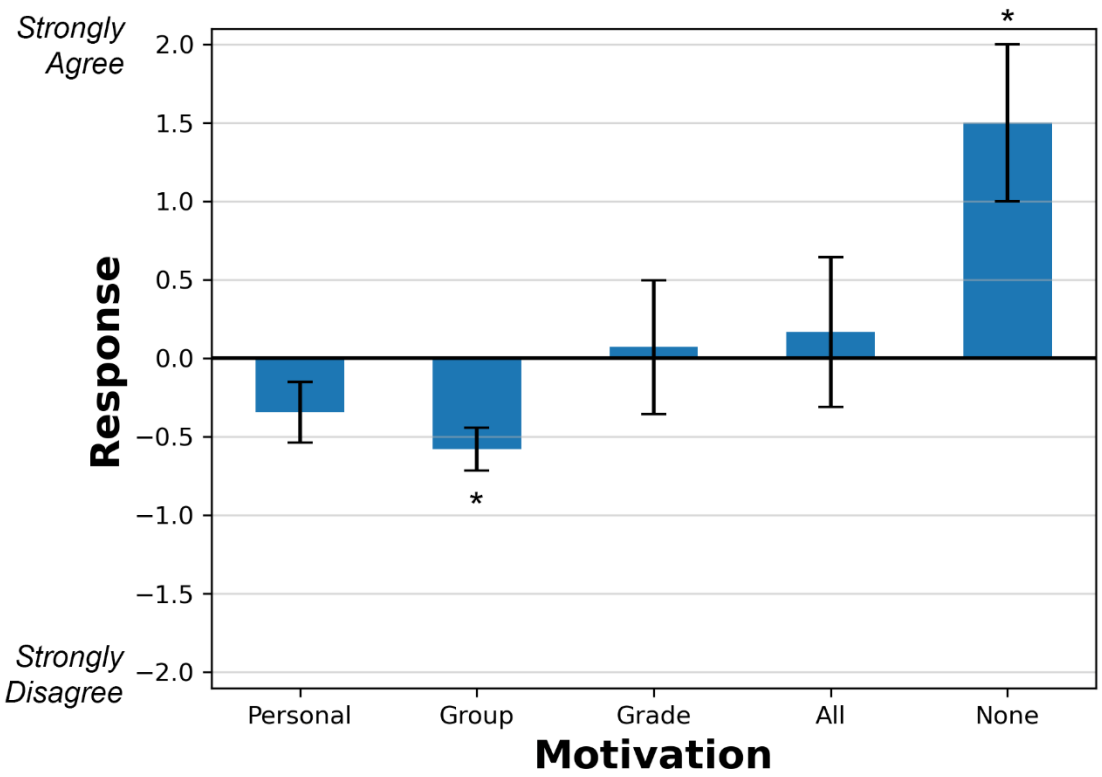

Figure 6: Student responses to "I feel that our group needed to communicate more often," which ranged from -2 (Strongly Disagree) to +2 (Strongly Agree). Students were sorted into one of the following motivation categories based on their response to their motivation for completing the project: Personal investment in the project (n = 32), group dynamic (n = 45), final grade (n = 14), all of the above (n = 6), or none of the above (n = 2). Means are reported with standard error bars with asterisks (*) denoting significant differences between means at $p < 0.05$.

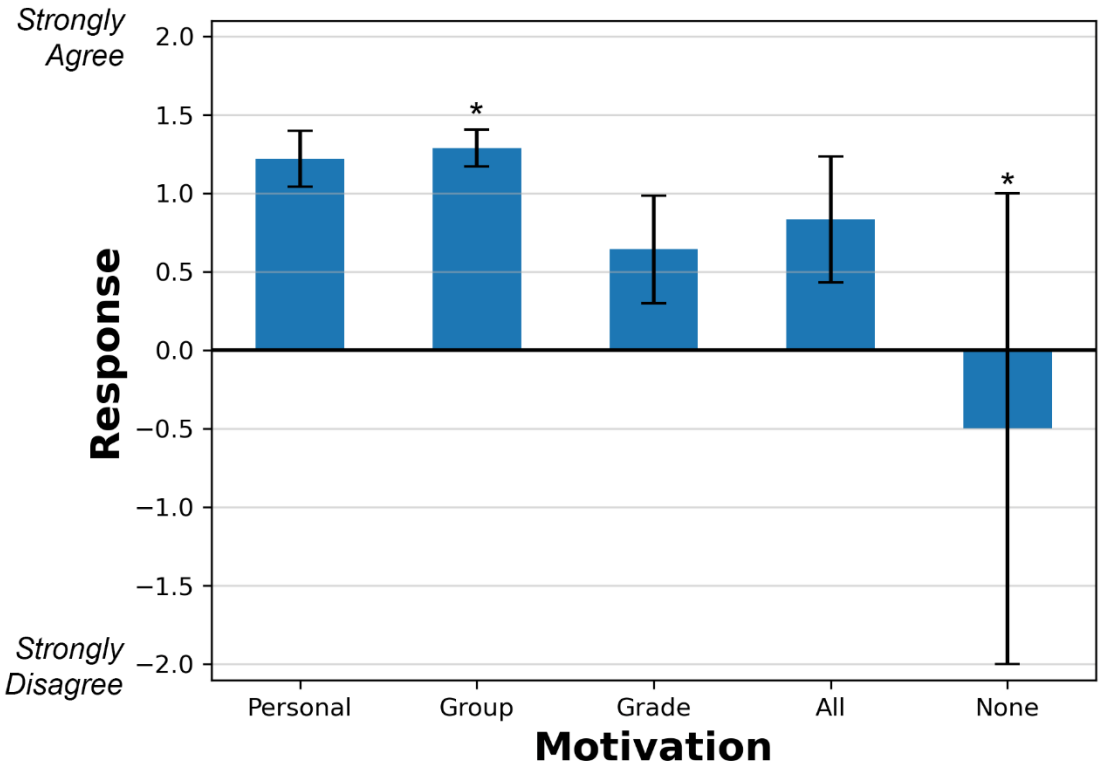

Figure 7: Student responses to "I got to know my groupmates this semester," which ranged from -2 (Strongly Disagree) to +2 (Strongly Agree). Students were sorted into oneof the following motivation categories based on their response to their motivation for completing the project: Personal investment in the project (n = 32), group dynamic (n = 45), final grade (n = 14), all of the above (n = 6), or none of the above (n = 2). Means are reported with standard error bars with asterisks (*) denoting significant differences between means at $p < 0.05$

Bonding in-person versus in a virtual environment

The results of the end-of-semester survey showed that students were able to communicate well with their teammates despite the virtual environment. However, particularly in open response questions, students demonstrated the difficulty of connecting on a deeper level and forming friendships in the online environment. One student response to the survey open-ended question, "How does this course stand out from the other courses you took this semester?" highlights this: "Most collaboration and interaction with other classmates, hands on, however since it was through Zoom, was quite hard to actually make friendships." Student preference for an in-person collaborative course is further highlighted by responses to an open-ended question asking students what can be improved for next year; 28% of the respondents specifically commented that the course could be improved by being held in-person.

Conclusions

EID101, the institution's first-year engineering design course, is designed to be a unique experience for first-year students because it provides in-class opportunities to actively engage in the design process through an original project and to form friendships and connections through group collaboration. For the Fall 2020, it was redesigned to include PD concepts in the curriculum and modifications for the virtual environment. A set of seven learning objectives were written by the faculty and shared assignments and workshops were created and implemented for all sections. To promote friendships and bonding and to assist faculty in project implementation, undergraduate TAs were assigned to each section. An End-of-Semester survey evaluated students' learning gains and experiences in the course, specifically focusing on new aspects of the course as part of the course's redesign and shift to online learning. From an ANOVA performed on the survey responses, three main results showed significant effects: (1) Students reported perceived gains in each of the learning objectives for projects with and without physically-built components; (2) TAs were successful in promoting communication and bonding amongst the first-year students; and (3) students' motivations in the course impacted group communication and bonding throughout the semester. Although the online virtual environment was successful at allowing groups to collaborate on their projects, students felt that deeper connections were harder to form in this environment.

Several takeaways from successful aspects of the course in the Fall 2020 can be carried on to future semesters, even when the course returns to in-person learning. First, the emphasis on PD concepts can continue to give students experience in problem formulation and iterating solutions. Second, the importance of student-to-student mentoring, demonstrated in the influence of the teaching assistants in the survey results, show that the Institution should continue to foster opportunities where students can learn from each other. Additionally, in future iterations of the course, faculty can specifically train student teaching assistants before the semester starts in how to mentor their groups. For the Fall 2021, the faculty intend to keep shared learning objectives, workshops, assignments throughout the course so that students have similar first-year experiences regardless of the section they are in or the project they work on.

Acknowledgments

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