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The role of Socio-technical Design Challenges in the Early Formation of Civil Engineers

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The Role of Sociotechnical Design Challenges in the Early Formation of Civil Engineers

Abstract

While design is common in first-year civil, construction, and environmental engineering (CCEE), it is uncommon to include sociotechnical design challenges. Design problems are ill-structured, meaning they have many possible solutions. Faculty sometimes make this more manageable by reducing the problem to technical aspects. However, research suggests sociotechnical problems—where technical aspects are related to social factors—help students engage with the problem. The objective of this study was to investigate the impact of two sociotechnical design challenges in a first-year CCEE course. We sought to understand how students experience framing and solving ill-structured sociotechnical design problems, guided by research question: To what extent does participating in socio-technical design challenges impact civil engineering student self-efficacy, identity, motivations and intention to persist? We conducted the study as design-based research, the hallmark method of the learning sciences, in which learning designs are tested under real-world conditions. The study was in a first-year CCEE course at University of New Mexico, a Hispanic-serving institution in the American Southwest. The 3-credit course was taught in two sections, with 92 enrolled, and 64 students providing informed consent for survey data analysis. The first challenge focused on environmental engineering as students addressed acid mine drainage in the Southwestern states. The second challenge focused on concrete mixes for the American Society of Civil Engineers concrete canoe competition. The challenges were structured in a series of deliverables addressing research of the problem, design and testing of a proposed solution, stakeholder and customer analysis, proposal of design solution that integrated data and stakeholder assessment, and final presentation. We collected student work and survey data and analyzed survey responses using either t-tests or descriptive statistics when appropriate. We found student self-efficacy significantly increased after both design challenges, identity as a civil engineer or construction manager significantly increased before and after the course, and intent to persist remained consistent from the beginning of the course to after the second challenge. Students were motivated to work on challenges that addressed environmental, humanitarian, and social justice causes. These findings demonstrate how design challenges can promote professional formation of civil engineers through development of engineering identity, sense of belonging to the profession, and motivations to pursue civil engineering and continue to persist in the degree and career.

Introduction

Early-stage undergraduate engineering courses often include open-ended design problems to give students an opportunity to practice engineering at the beginning of their academic pathway. Problems have two attributes: they are an unknown entity in some situation, and solving the unknown entity will have social, cultural or intellectual value [1]. Most fundamental science and engineering classes outside of design courses feature problems that are *complex* in that they have many interrelated variables; they are also *well-structured.* These types of problems have a known correct answer and can be solved directly and efficiently [2]. Engineering in the real world, however, features complex *ill-structured* problems rooted in social, historical or cultural contexts. In ill-structured problems, "goals are vaguely defined; no constraints may be stated, little is known about how to solve the problem; there is no consensual agreement on what constitutes a good solution; and information available to the problem solved is prodigious, but incomplete, inaccurate, or ambiguous" [1]. These problems require designers to make decisions about not just how to solve the problem but what aspects of the problem are important, what stakeholders should be considered, and what the attributes of a successful solution should be [3]. Design in the classroom supports engineering students to develop important professional skills and increase their self-efficacy and intent to persist in engineering [4], [5]. This particularly impacts minoritized students in engineering by supporting identify development [6].

Recent practices in engineering education design involve use of open-ended socio-technical design problems, where technical aspects are related to sociocultural and economic frameworks [7]. Socio-technical problems can emphasize social justice, humanitarian practice, human and natural environments, and stakeholder engagement. Engineering faculty must work to build educative practices that help scaffold students to design solutions that are purposeful and thoughtful in addressing a social challenge and specific population [8]. This can be done via an educative design framework. Design problems can be assessed based on relevance (problems that connect to students' lived experiences), sociotechnical complexity (social factors intersect with technical factors), low-bar entry (problems that are accessible and understandable), and non-deterministic high ceiling (there is no single solution to the problem) [9].

The goal of this paper is to use the educative design framework and design learning to implement two socio-technical design challenges in an early-stage undergraduate civil engineering course and determine the impact of the course on the growth and formation of civil engineering and construction management students. Our research question is: To what extent does participating in socio-technical design challenges impact civil engineering and construction management student self-efficacy, identity, motivations and intention to persist?

Methods

To answer this research question, we conducted the study as first-cycle design-based research (DBR). This method focuses on iterative, contextualized research that allows for the deep understanding of interventions [10].

Course

Civil Engineering Design is a 3-credit, entry-level course at the University of New Mexico, an R1 Hispanic Serving Institution in the Southwestern United States. The course is offered in the Department of Civil, Construction and Environmental Engineering, which has ABET accredited Civil Engineering, Construction Engineering, and Construction Management programs. The course is taught every semester to both civil engineering (CE) and construction management (CM) students. The purpose of the course is to provide an introduction to the fields of civil, construction and environmental engineering and construction management. Students learn about: the process of being a civil engineer or construction manager; the scope of careers open to graduates; some of the procedures and methods used in engineering design; how to work effectively on open-ended problems under constraints of time; how to work effectively on small teams and communicate ideas; and how to develop an understanding of professional and ethical responsibility. The previous iterations of the course featured guest speakers from academia and industry, individual homework assignments where students reflected on what they learned from the speakers, and a group project to design a sustainable human habitat on the planet Mars. In Fall 2023, a new instructional team (1 lead professor, 2 undergraduate and 1 graduate course assistants, and 1 education specialist) was mentored by an instructional team in the Chemical and Biological Engineering Department to redesign the course. The course redesign features two group socio-technical design challenges and weekly individual homework for students to research disciplinary sub-specialties and career opportunities. During the first month of instruction, students are oriented to campus, the major, resources within the department and School of Engineering, and learn about engineering ethics and environmental justice. The subsequent two months of class time are used for students to work on their design projects, including group deliverables and presentations. In the final two weeks of the course, students deliver individual presentations on the civil engineering/construction management major or field.

Socio-technical design challenges

The course was structured as two group-based design challenges that each took one month to complete. Each challenge was structured in a series of deliverables that were worked on as a team to address research of the problem, design and test of a proposed solution, stakeholder and customer analysis, proposal of design solution that integrated data and stakeholder assessment, and final presentation. The Acid Mine Drainage challenge has been successfully implemented in the Introductory Chemical and Biological Engineering course at the University for the past five years and was adapted verbatim for this Civil Engineering course since the core concepts learned are equally applicable to students in both courses [9]. The Concrete Canoe challenge was newly developed by the instructional team for this course. The two design challenges are described briefly below.

<u>Design Challenge 1: Acid Mine Drainage in Southwestern states</u>

In the Acid Mine Drainage (AMD) Design Challenge, students must propose a water treatment emergency response system for a specific rural community that is impacted by AMD. This design problem was inspired by regional events such as the Gold King Mine Spill that occurred in 2015, where over 3 million gallons of AMD contaminated water was accidentally released into the Animas River, impacting water supplies for rural and Indigenous communities. In New Mexico, there are 15,000 abandoned mines, many of which are co-located with vulnerable communities, and there is risk of current and future environmental contamination [11]. Students work in teams of 3-4 to research AMD, the Gold King Mine Spill, and novel treatment options. Next, they plan a lab experiment to raise the pH of 200 mL of AMD water from 3 (acidic) to 7 (neutral), using their choice of 4 materials: limestone, calcium carbonate, activated carbon, and soda ash. Students then test their proposed experiment in a wet-chemistry laboratory, record data on findings, and have an opportunity to iterate on their materials list and try the experiment again. Outside of the lab, students research a community in New Mexico that could be impacted by AMD and apply empathy perspectives to consider all stakeholders who may be involved (community members, farmers, government employees, etc.). The final proposed solution for treatment integrates both the lab experiment and the community stakeholder needs assessment.

<u>Design Challenge 2: Concrete Canoe</u>

The American Society of Civil Engineers (ASCE) holds an annual concrete canoe competition where student groups from universities across the U.S. design, build and race a canoe made with concrete. The competition has been held annually since 1988 and touted to combine engineering excellence, hydrodynamic design, and racing technique. The engineering design competition allows students to experience aspects of real-life engineering and introduces them to project management, design, analysis and testing, and collaboration among teammates and with professional engineers. Teams are not only competing against each other in a given year but are learning from and building upon experiences and knowledge from past years [12].

The concrete canoe problem can be considered in the educative design framework: the problem is *relevant* to student's experiences in Civil Engineering; it is *socio-technical* in that it engages a stakeholder (ASCE), has students consider the humans who would be building and testing the canoe and the environment and constraints in which they would be working, including planning for interpersonal aspects such teamwork and project management; it is *accessible* to both civil engineers and construction managers; and there are a *myriad of solutions* in terms of concrete mixes and canoe designs that could be proposed.

We adapted the large concrete canoe competition into a smaller design challenge that focused on the concrete mix design and written report parts of the competition and could be completed in one month. Students work on teams of 3-4 to research canoe designs, properties of concrete, and concrete fracture mechanics. Next, they plan several concrete mix designs, using their choice of four materials: water, cement, sand, and gravel. Students then spend two days in the lab: on day 1, they make concrete mixes and pour them into an ice cube tray mold to set; on day 2, they extract their concrete cubes, perform float and fracture tests, and record data. Outside of the lab, students research the ASCE Concrete Canoe competition, analyze elements of the technical report that is submitted during the competition, and prepare a bid package to present to the current year's ASCE team. The bid package consists of a letter of intent, proposal of which concrete mix the team should choose to make their full canoe, schedule of tasks with timeline to complete building and testing, and a detailed cost analysis. Final group presentations were delivered in front of the class as well as representatives from the university's ASCE student chapter.

Data collection

We collected data on the two sections of the course taught in the Fall 2023 semester. Of the 92 students enrolled in the course, 64 consented to be in the study. Consent was collected following the study's approval by the internal review board (IRB). Responses were collected on a 7-point Likert scale. Students were given 4 surveys across the semester: a "pre" survey during the first two weeks of the course, a framing agency survey ("D1") given after the first design challenge (Acid Mine Drainage), a framing agency survey ("D2") given after the second design challenge (Concrete Canoe), and a "post" survey given the last week of class. Surveys included Likert-scale questions on self-efficacy, identity, and intent to persist that are supported by pre-existing literature [13]–[15]. Additional questions on motivators, relevance of design challenges, and engineering skills were added for general instructor interest.

Self-Efficacy Measured Across the Semester-Long Course

Four questions were asked to gauge self-efficacy (how certain are you that you can: identify a design need, develop a design solution, evaluate and test a design, recognize changes needed for a design solution to work). Responses were collected on a Likert-scale, where 1 indicated "completely uncertain" and 7 indicated "completely certain." **Table 1** shows that responses to all four questions could be grouped into one self-efficacy variable. Self-efficacy was measured on all four surveys (pre, D1, D2, post).

Importance of Skills Learned for Civil Engineering and Construction Management

After both design challenges, students were asked about importance of skills for civil engineering and construction management (background research, experimental design, data collection and repeatability, cost analysis, collaboration, written communication, oral communication, community/stakeholder engagement). Responses were obtained on a Likert-scale of 1 to 7, where 1 indicated "very unimportant" and 7 indicated "very important." The average score after the first design challenge across all 8 categories ranged only minimally between 6.38 – 6.58, and after the second design challenge ranged 6.19 – 6.41. We grouped the four technical skills (research, experiment, data, repeatability) and four professional skills (collaboration, written, oral, stakeholder) to calculate a mean and perform a paired samples t-test across groups.

Engineering and Construction Management Identity

This introductory Civil Engineering course was unique in that it contained students from both civil engineering and construction management majors. The pre and post surveys asked students about their engineering identity and construction management identity separately. Three identity factors were measured (my parents, relatives and friends see me as an engineering/construction management person; my instructors see me as an engineering/construction management person; I feel like I belong in engineering/construction management). Responses were collected on a Likert-scale, where 1 indicated "strongly disagree" and 7 indicated "strongly agree." Factor analysis indicated that responses to these questions factored into separate identity variables per major (**Table 1**). The analysis was performed for responses for the whole class to maintain statistical power.

Intent to Persist Within the Degree and Career

Intent to persist (in the degree, in a career) was measured separately for engineering and construction management. Two statements were measured to gauge intention to persist (I intend to: complete a degree in engineering/construction management, stay in engineering/construction management for at least 3 years after I graduate—as a professional, a graduate student, and/or researcher). Responses were collected on a Likert-scale, where 1 indicated "strongly disagree" and 7 indicated "strongly agree." Intent to persist in engineering was measured in all four surveys (pre, D1, D2, post), while intent to persist in construction management was only measured in two surveys (pre, post).

Motivators for Working on Design Challenges

Five motivational factors were evaluated in the pre and post surveys (how motivated would you be to work on a design challenge if it could: help the environment, be highly innovative and novel, help people or meet humanitarian needs, make money for you or your company, address inequities or social justice). Responses were collected on a Likert-scale, where 1 indicated “not motivated at all” and 6 indicated “highly motivated.”

Relevance of Design Challenges to Civil Engineering and Construction Management Students

Two design challenges were piloted in this course. The Acid Mine Drainage (AMD) challenge was adapted from a similar course taught to chemical and biological engineers, while the Concrete Canoe challenge was newly developed for this course. Students were asked about the relevance of the design challenges (how relevant was the design challenge to: the work that civil engineers do, the work that construction managers do, to your own interests). Responses were collected on a Likert-scale, where 1 indicated “completely irrelevant” and 7 indicated “very relevant.”

Data Analysis

Factor Analysis

Four categories of questions, each with three to five sub questions, were included within the surveys. These categories were: self-efficacy, engineering identity, construction management identity, and motivations to work on a design challenge. We aimed to determine if survey questions could statistically be collated into these categorical groups for analysis. Thus, we performed exploratory factor analysis (EFA). This is used to investigate the validity of data provided by surveys and evaluate whether the survey measures what it intends to measure by assessing the relationship between variables. There are established guidelines for inclusion or exclusion of a factor. Questions that grouped together with factor loadings greater than 0.4 or less than –0.4 and did not cross-load between factors were considered acceptable. We retained factors that had a Cronbach's alpha ≥ 0.6, which is generally acceptable in education literature [16]. Factors that met these criteria were then averaged into single scores for analysis [17].

Paired t-test

Paired samples t-tests with 95% confidence interval were performed to compare factor means across all surveys [18], [19]. A p-value of less than 0.05 was considered statistically significant. Cohen’s d effect size was calculated to relate the mean differences to statistical variability [20]. Paired samples t-tests and Cohen’s d effect size are reported for survey questions that factored together for increased statistical power **(Table 1)**. Additional paired sample t-tests were performed for pre and post questions to skills learned and intent to persist.

Descriptive statistics

Where a paired t-test could not be performed due to small sample size or inability to factor Likert questions, descriptive statistics were performed. Means are used to indicate the central tendency for individual questions. Responses to each Likert scale option (1-7) are displayed as frequencies or percentages of respondents who chose a given answer for a question.

Results and Discussion

Factor Analysis to Create Variable Categories

Results of the pattern matrix from the factor analysis are shown in **Table 1**. Per the results of the factor analysis, the four self-efficacy questions (confidence to identify a design need, identify a design solution, evaluate a design, change a design) were grouped into one self-efficacy variable ($\alpha = 0.921$); the three engineering identity questions (perception as an engineering person by friends and family, instructors, and themselves) were grouped into one engineering identity variable ($\alpha = 0.654$); the three construction management identity questions (perception as a construction management person by friends and family, instructors, and themselves) were grouped into one construction management identity variable ($\alpha = 0.856$), and five motivators questions (environmental, innovation, humanitarian, money, social justice) were grouped into one motivator variable ($\alpha = 0.866$).

Table 1: Pattern matrix for factor analysis showing groupings of questions within a similar category.

Category	Question stem	Individual questions	Factor loading			
			1	2	3	4
Motivation to work on a design challenge (α =0.866)	How motivated would you be to work on a design challenge if you thought the design...	Could help the environment or result in a more sustainable/green solution	0.867	0.013	-0.127	-0.157
		Could be highly innovative and novel	0.751	-0.065	0.069	0.252
		Could help people/ meet humanitarian needs	0.901	0.033	-0.068	-0.041
		Could make money for you/ the company you work for	0.620	-0.071	0.119	0.232
		Could address inequities or a social injustice	0.894	0.056	0.014	-0.166
Self-Efficacy (α=0.921)	How certain or uncertain are you that you can…	Identify a design need	0.111	0.865	0.000	0.062
		Develop design solutions	0.075	0.958	-0.002	-0.034
		Evaluate and test a design	-0.086	0.867	0.013	0.129
		Recognize changes needed for a design solution to work	-0.112	0.873	-0.005	-0.044
Constr. Mgmt. (CM) identity (α =0.856)	Please rate your agreement with the statements	My parents, relatives, and friends see me as a CM person	-0.075	0.068	0.915	-0.045
		My instructors see me as a CM person	0.034	-0.127	0.777	0.162
		I feel like I belong in CM	0.015	0.040	0.953	-0.159
Engr. Identity (α =0.654)	Please rate your agreement with the statements	My parents, relatives, and friends see me as an engineering person	-0.123	-0.051	-0.154	0.845
		My instructors see me as an engineering person	-0.012	0.120	0.013	0.693
		I feel like I belong in engineering	0.157	0.052	0.074	0.705

Self-Efficacy Measured Across the Semester-Long Course

Significant change was seen in self-efficacy between the pre and post surveys, pre and D1 surveys, and D1 and D2 surveys, while no significant change was seen between D2 and post surveys. **Figure 1** shows self-efficacy increased most significantly after the first design challenge (mean of pre = 4.59, mean of D1 = 5.47, $p < 0.001$, effect size = 0.503), indicating that it was strongly effective in building student self-confidence to approach and solve a design problem. Self-efficacy continued to increase between the first and second design challenges (mean of D2 = 5.91, $p = 0.025$, effect size = 0.305), indicating continued growth and that the skills learned were reinforced by the second design challenge. No significant change was seen between the second design challenge and post surveys (mean of post = 6.08, $p = 0.074$, effect size = 0.245). The post survey was given two weeks after the D2 survey and no additional design challenges were performed in the interim, which might explain why there was not a significant change and the means remained similar.

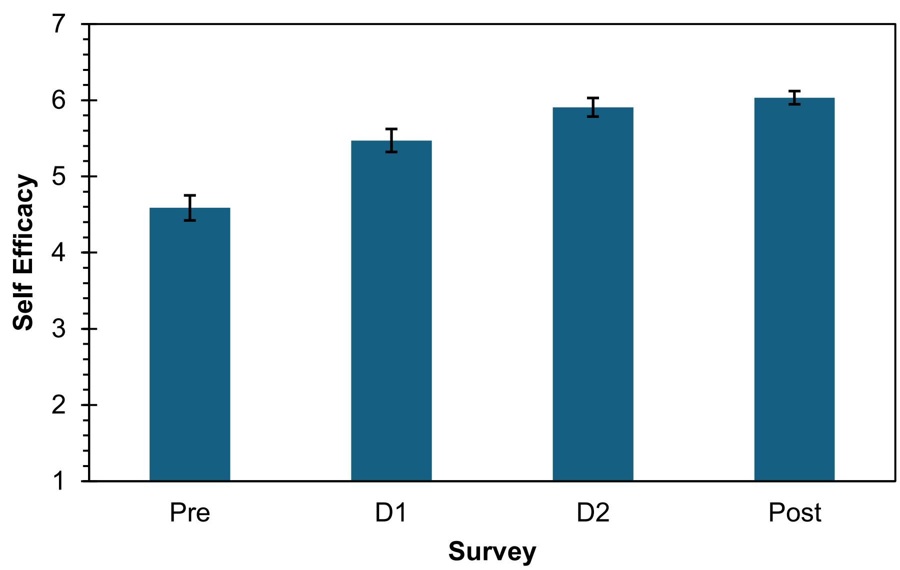

Figure 1: Means of self-efficacy scores measured on surveys pre-course (n = 63), first design challenge (D1, n = 63), second design challenge (D2, n = 57), and post-course (n = 59). Error bars show standard error. Means are collected from Likert-scale responses from 1-7, where 1 indicates “completely uncertain” and 7 indicates “completely certain.” Self-efficacy scores were averaged over 4 questions as described in the factor analysis.

Importance of Skills Learned for Civil Engineering and Construction Management

After the first design challenge, there was no significant difference between the scored importance of technical and professional skills (mean technical = 6.5, mean professional = 6.4, $p = 0.153$, effect size = 0.432). A similar trend was observed after the second challenge (mean technical = 6.38, mean professional = 6.28, $p = 0.52$, effect size = 0.484). This would indicate that civil engineering and construction management students value both technical and professional skills as fundamental to their degree and career. A limitation of this analysis is that this question was not asked on the pre-course survey. Therefore, a potential change due to the first design challenge could not be measured.

Student perception of the importance of technical skills can be related to their self-efficacy. The task of performing background research can build students' confidence in identifying a design need. Determining experimental design, and performing data collection and cost analysis, tie to developing a design solution and evaluating and testing a design. Repeatability relates to recognizing changes for a design solution to work.

Engineering and Construction Management Identity

This introductory Civil Engineering course was unique in that it contained students from both civil engineering and construction management majors. All students were asked about engineering identity and construction management identity. Analysis was performed for responses for the whole class to maintain statistical power due to the small number of construction management students in the course. Identity significantly increased for both engineering ($p = 0.004$, effect size = 0.393) and construction management ($p = 0.013$, effect size = 0.338). **Figure 2** shows engineering identity on both pre and post surveys (mean pre = 5.29, mean post = 5.69, $n = 57$) was a full unit higher than construction management identity (mean pre = 4.30, mean post = 4.71, $n = 58$). This may be because there were more engineering students in the course than construction management students (60:40 CE:CM ratio). Additional explanation of these results could include that the course was designed by civil engineers, design deliverables were tailored for civil engineering, and course homework focused on the six specialization areas within civil engineering.

In future work, a larger sample size across multiple course offerings could be surveyed to overcome the limitation of having all students answer both engineering and construction management questions regardless of their major. An average and t-test could be performed on only civil engineering students answering civil engineering identity questions, and only construction management students answering construction management identity questions given there was a larger sample size for analysis.

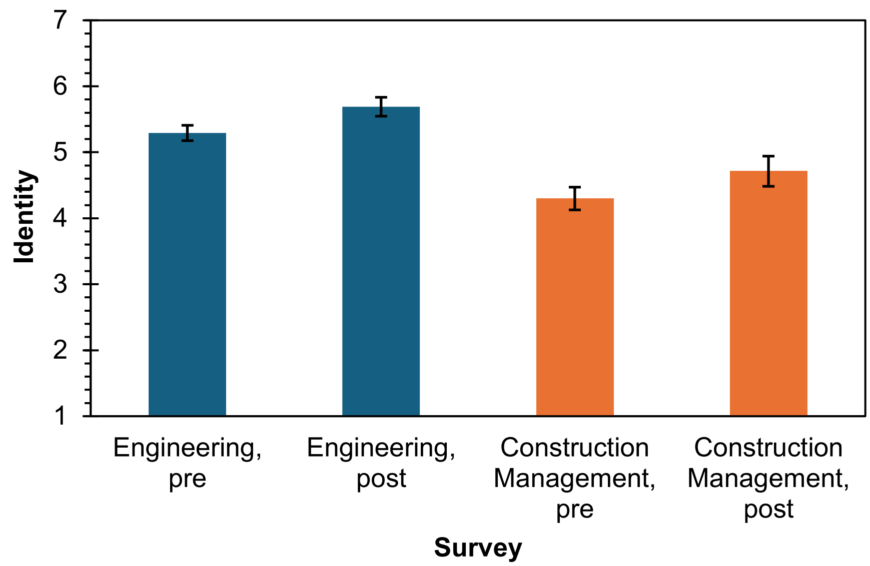

Figure 2: Means of identity scores measured on surveys pre-course and post-course for engineering (n = 57) and construction management (n = 58). Error bars show standard error. Means are collected from Likert-scale responses from 1-7, where 1 indicates "strongly disagree" and 7 indicates "strongly agree." Identity scores were averaged over 3 questions as described in the factor analysis.

Intent to Persist Within the Degree and Career

Figure 3 shows that the response mean values for intent to persist in the engineering degree increased between the pre (mean = 5.84), D1 (mean = 6.16), and D2 (mean = 6.23) surveys. However, paired samples t-test indicated no significant change (pre to D1 $p = 0.273$, D1 to D2 $p = 0.892$). Additionally, intent to persist in an engineering degree significantly decreased by the post survey (mean = 5.61, $p = 0.022$, effect size = 1.948). Similar trends were observed for intent to persist in an engineering career (mean pre = 5.48, D1 = 5.79, D2 = 5.95, post = 5.33) with no significant change between the pre, D1 and D2 surveys, but a significant decrease between the D2 and post surveys ($p = 0.012$, effect size = 1.893). The mean also decreased between pre and post surveys for intent to persist in a construction management degree (mean pre = 4.23, post = 4.07) and career (mean pre = 4.09, post = 4.00), but these changes were not significant ($p = 0.940$ and $p= 0.941$ respectively).

It is interesting to note that intent to persist remained consistent throughout the semester-long course, and only decreased at the very end. This could be due to a myriad of reasons, including facing looming challenges such as upcoming finals, final presentations in this and other courses, loss of motivation, and other end of semester struggles. Future iterations of this course and survey will ask students about what challenges and barriers they faced at different times throughout the course to better understand this change.

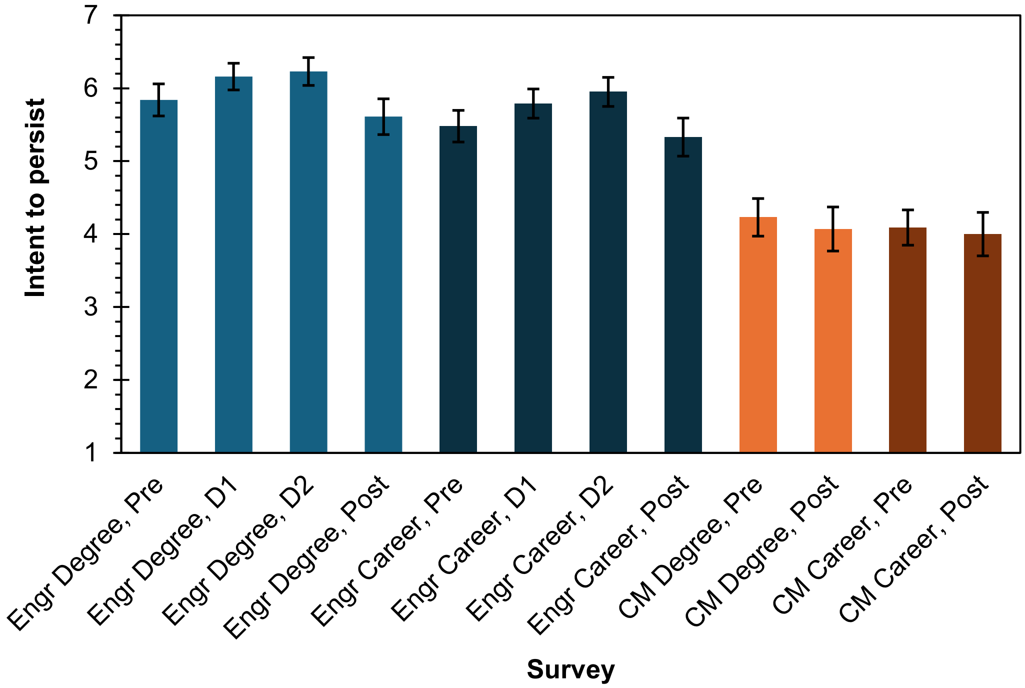

Figure 3: Means of intent to persist scores measured for engineering (Engr) on surveys pre-course (degree n = 64, career n = 64), after the first design challenge (D1, degree n = 64, career n = 63), after the second design challenge (D2, degree n = 57, career n = 57), and post-course (degree n = 61, career n = 60) and construction management (CM) on surveys pre-course (degree n = 64, career n = 64) and post-course (degree n = 59, career n = 60). Error bars show standard error. Means are collected from Likert-scale responses from 1-7, where 1 indicates "strongly disagree" and 7 indicates "strongly agree."

Motivators for Working on Design Challenges

Descriptive statistics of frequencies and average scores for motivators to peruse civil engineering and construction management are shown in **Figure 4**. In the pre survey, making money and meeting humanitarian needs were ranked slightly higher than other factors. By the end of class, motivations for all 5 factors increased, with the largest increases seen for helping the environment and meeting humanitarian needs. These results show that civil engineering and construction management students are motivated by several factors, not just money. In fact, the motivation to make money did not have a large difference in mean value between pre and post surveys, while all other factors had mean value increase by 0.27 – 0.41.

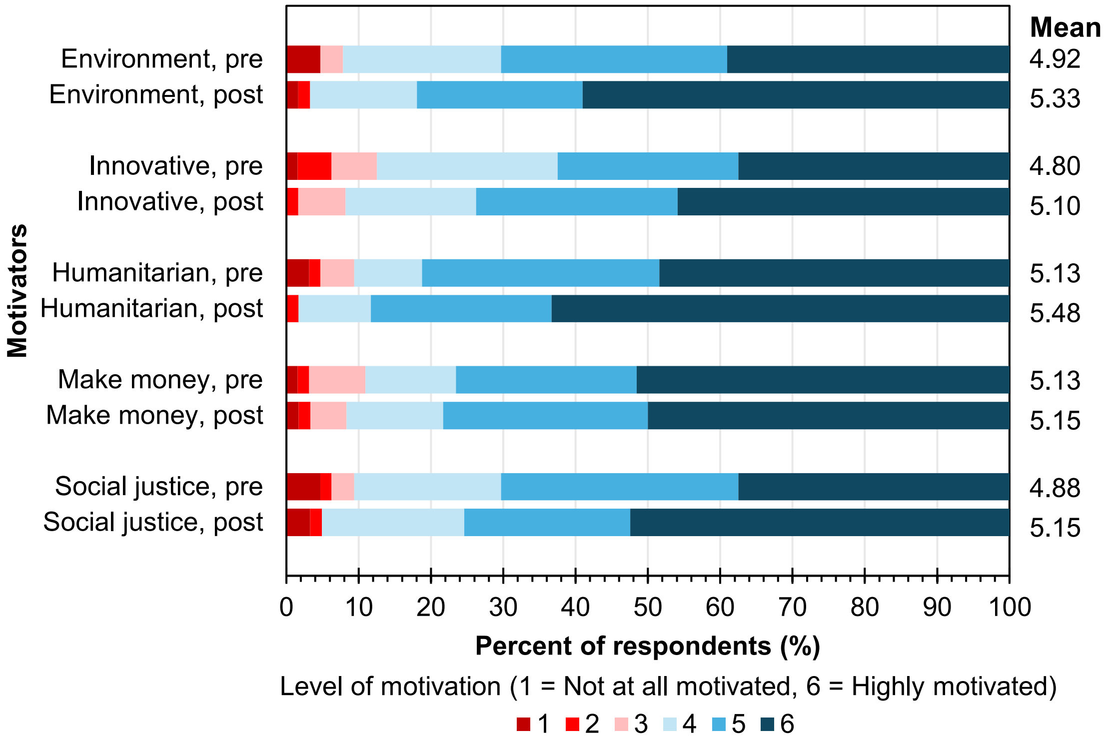

Figure 4: Motivational factors to working on a design challenge, measured in pre and post course surveys. Each section of bar represents the percentage of respondents who chose a given answer for a question, where 1 = "not at all motivated" and 6 = "highly motivated". To the right of each bar is the Likert-scale mean. Total number of respondents on pre survey = 64, post survey = 61.

Relevance of Design Challenges to Civil Engineering and Construction Management Students

Descriptive statistics of frequencies and average scores for each motivator are shown in **Figure 5**. Concrete canoe (CC) was seen as relevant to both civil engineering and construction management (mean CE = 6.05, mean CM = 6.13), while AMD was seen as more relevant to civil than construction (mean CE = 6.20, mean CM = 5.38). Both challenges had similar distribution of responses for relevance to self (mean AMD = 5.40, mean CC = 5.44). The AMD challenge had deliverables that were specifically geared towards solving engineering problems in a socio-technical manner; it tasked students with proposing materials and a treatment system to treat AMD wastewater in a specific rural community. Meanwhile, the concrete canoe challenge added specific construction management-related tasks on top of proposing materials for the ASCE Concrete Canoe team; it tasked students with calculating cost of the full canoe and scheduling tasks for the ASCE team to complete and test the canoe.

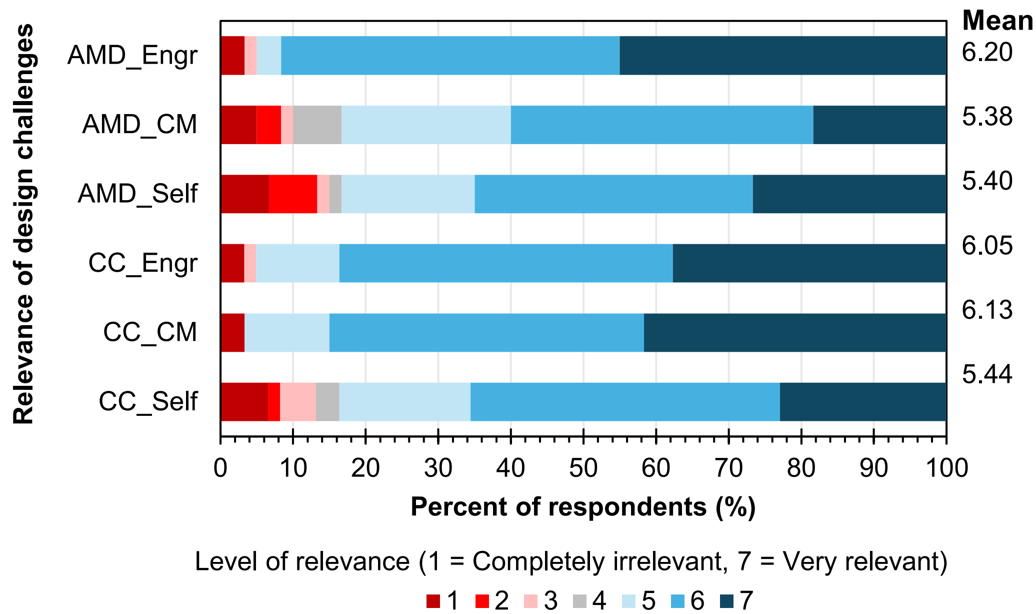

Figure 5: Relevance of acid mine drainage (AMD) and concrete canoe (CC) design challenges to the work civil engineers do (Engr), the work construction managers do (CM), and their own interests (self). Each section of the bar represents the percentage of respondents who chose a given answer for a question, where 1 = "completely irrelevant", and 7 = "very relevant". To the right of each bar is the Likert-scale mean. Total number of respondents for the AMD questions = 60, for CC questions = 61.

These results indicate that having the two design challenges that approach different fields of civil and construction management is overall beneficial for a mixed class of students from both majors. Civil engineering students are able to learn about concepts that construction managers will cover in further depth in their future courses, while construction managers are able to appreciate how civil engineers seek design solutions. While these students will only overlap in a few courses over their undergraduate degree (e.g., Engineering Economics), they are paired together again in their final senior capstone design course. In that course, the students work with a project mentor from a local engineering firm to design a civil engineering system (e.g., wastewater treatment plant, new transportation corridor, bridge reconstruction), and construction management students act as project managers to complete scheduling and cost estimates. The early-stage course discussed in this paper can serve as a preview to students of how their final capstone project team can operate.

Limitations

This research study was conducted for the first time within this introductory undergraduate civil engineering course at the university. There was not any data collected from prior iterations of this course. Therefore, we cannot fully assess how the newly designed course impacted students across cohorts experiencing different versions of the course.

As this was the first iteration of this course, the sample size is for one semester worth of students. Not all students submitted their Informed Consent forms or consented to participating in the study (70% consented). The total sample size was 64 students, with between 55 and 64 students responding to each survey. With the addition of future semester cohorts of students experiencing this new redesigned course, more data can be processed and statistical power can be increased.

This course, while titled Civil Engineering Design, is required for both civil engineering and construction management majors. The ratio of CE to CM students was 60:40. Responses to questions related to engineering and construction management identity were not separated by intended major due to the low sample size. We also did not track whether students switched between the two majors during the semester. With a larger sample size, future analysis could be split to only look at engineering student identity among engineering majors, and construction management identity among CM majors.

This study did not address cognitive bias that could be present in students' responses to self-efficacy and intent to persist assessments. The Dunning-Kruger effect, wherein a person's lack of knowledge and skill in a certain area leads to their overestimating their own abilities, could be at play among early-stage undergraduate students who have not yet been challenged by the degree program. It could be interesting to follow this cohort of students both simultaneously in other courses such as math, and throughout their degree, to determine how responses to these questions change, and track alongside retention/attrition rates.

Conclusions

This study aimed to introduce sociotechnical design challenges to early-stage undergraduate civil engineering and construction management students. Preliminary findings from the first semester cohort of students taking this course show that it had a positive impact on self-efficacy, identity, intention to persist, and motivation to pursue civil engineering to address environmental, humanitarian, and social justice causes. Future iterations of this course will repeat the same two design challenges (acid mine drainage, concrete canoe) across different cohorts and with different instructional teams to increase statistical power of analysis and determine if results remain similar across cohorts. Input from students will continue to be received regarding relevance of the two challenges to civil engineering, construction management and themselves. Future design challenges may be developed and integrated into the course based on this feedback.

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