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Creating a Pipeline of Civil Engineering Students Through Innovative Summer Course

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ABSTRACT

Domestically, the gap between civil engineering graduates and projected needed civil engineers continues to grow. With recent investment in infrastructure through the Infrastructure Investment and Jobs Act, additional civil engineers will be needed to design, build, and maintain civil infrastructure. An innovative summer course at Purdue University aims to decrease the space between the needed civil engineers and students graduating with an undergraduate civil engineering degree by helping pre-college students understand what types of problems civil engineers solve. This one-week course focuses on exposing students to both the depth and breadth of civil engineering and has explored various topics, including resiliency versus sustainability, design for tomorrow's loads and problems, the use of novel technologies in engineering, and design for extreme (and extraterrestrial) habitats. Innovative activities include using drones for aerial photography and mapping, identifying tension and compression loads by building a 3D bridge model, tours to Purdue's innovative research facilities, reviewing the infrastructure around them and proposing novel improvements, and participating in activities in the classroom like debates about autonomous vehicle and jigsaw activities. The authors anticipate similar programs could be instituted at universities and not-for-profits across the country to expose diverse students to civil engineering as a career and to the complex, multi-dimensional problems civil engineers get to solve every day. In addition to the means and methods of this course, this paper evaluates the course's effectiveness by reviewing course survey data, student projects, and student outcomes. This analysis indicates that students left the course with greater knowledge of the topics discussed and pointed to various hands-on activities as their favorites. Furthermore, students self-identified as having a greater interest in civil engineering topics and engineering as a career. Reviewing the longitudinal data indicated that many students are enrolling in engineering in college, but additional time is needed to evaluate the type of engineering and post-graduation outcomes.

Tags: civil engineering, future engineers, foster interest, hands-on activities, summer course, engineering pipeline

INTRODUCTION

Civil engineers are critical to continued infrastructure investment, growth, and development. Currently, an estimated 307,570 people are employed in civil engineering jobs across the U.S. [1], and approximately 21,500 domestic degrees in civil engineering were awarded in 2020 and 2021 [2], [3]. Similarly, 21,200 civil engineering job openings are projected each year due to workers who transfer or retire from 2022 to 2032 [4] but an additional 883,600 jobs are anticipated due to the impact of the Infrastructure Investment and Jobs Act by 2030 [5]. Without intervention, these conditions will lead to an increasing shortage of civil engineering professionals, resulting in delays in infrastructure updates and negative economic impacts [6]. This paper discusses one program at Purdue University aimed at creating a pipeline of future civil engineers. Through this course, the authors sought to expose students to the breadth of civil engineering fields and inspire students to pursue civil engineering careers through their undergraduate education and beyond.

BACKGROUND

Workforce development encompasses policies and programs that facilitate learning for employment [7]. Workforce development is tied to education since the early years of academic institutions. From the Morrill Acts in the 1800s to the most recent Workforce Innovation and Opportunity Act (2014), the U.S. Congress has continued to adopt and update workforce development legislation for centuries. However, a decade has passed since the last federal action focused directly on workforce development. In the absence of additional public policy intervention, educators and trainers themselves need to address the requirements of a changing workforce to narrow the gap between needed civil engineers and existing pipelines.

Many situational factors have changed through the last decade, including the role of technology, workforce demographics, labor market conditions, and research-based recommendations for workforce development. First, as technology advances, workers need new skills and competencies to use these new technologies. These advances, in turn, require updates to training programs and employee services [8]. Second, changing workforce demographics, including an aging workforce and greater workforce diversity, require adaptable strategies to meet the varied needs of students and workers and maximize labor market participation [9]. Third, changes in labor market demand, such as the jobs created by infrastructure investment and remote work, call for flexible and innovative workforce solutions [10]. Finally, recent research has changed recommendations for workforce development. For example, recent research has suggested reducing barriers for underrepresented and disadvantaged groups, including ensuring equitable access to job opportunities and career advancement, results in enhanced economic growth [11]. These challenges highlight the need for educators willing to address them in the classroom and an innovative curriculum.

Taking a closer look at civil engineering, the American Society of Civil Engineers (ASCE) has highlighted that civil engineering firms are struggling to hire and retain skilled workers needed for the surge in infrastructure work, exacerbated by the influx of federal funding from the Infrastructure Investment and Jobs Act and the Inflation Reduction Act [12]. Moreover, many factors have been the cause of this shortage in the engineering workforce. The American Society of Mechanical Engineers (ASME) points out many engineers left the field during the Great Resignation in early 2021, either switching careers or retiring. This situation has led to a bidding war for top talent in sectors like manufacturing, where there is an acute shortage of experienced engineers [13]. ASCE attributes the shortage to multiple factors, including demographic shifts, the retirement of the baby-boom generation, and not enough new talent pursuing engineering degrees [12]. ASCE suggests that the engineering sector may not have effectively advertised the profession to attract students, leading potential engineers to pursue other careers. Even after effectively recruiting engineers, some companies struggle to retain them. The Structural Engineering Engagement and Equity (SE3) Committee reported that 56% of respondents on a nationwide survey considered leaving the profession to seek better work-life balance, less stress, and higher pay [14].

Several studies have identified factors that are correlated with students not pursuing engineering as a career. Some factors determined in [15], [16] and are presented below:

- Perception of STEM fields, like engineering, as too difficult.
- Considerable time commitment outside of the classroom, approximately double the time outside of class required for majors like communications, marketing, and criminal justice.
- Higher dropout rate for engineering students than for most majors.
- Lack of preparedness for the level of rigor involved in engineering programs.
- Student interests do not match college engineering degree programs.

Many of these factors can be addressed in the K-12 education system or from higher education institutions in a pre-college setting. In general, the literature presents two types of outreach activities: (1) student-oriented engineering outreach programs and (2) teacher training programs in engineering. Examples of student outreach programs include programs targeting middle school students [17], high school students [18], and underrepresented minorities [19]. Other programs train and develop materials for K-12 educators, including instructional models [20], classroom experiments [21], recruitment activities [22], and professional development workshops [23].

This study evaluates a summer course for pre-college students as an instrument to mitigate some of the identified factors why students are not choosing engineering as a career. This paper describes the practices, challenges, and evaluation of a pre-college summer course to foster interest in civil engineering. This course addresses the workforce (and student) shortage challenge before students enter college by incorporating a stimulating curriculum, demystifying the civil engineering profession, and improving students' engineering knowledge to succeed in their academic careers.

COURSE CONTENT

The course content was tailored to promote student interest in civil engineering and help increase the pipeline of students pursuing engineering degrees. For the last four years (2020-2024), the one-week course was offered to groups of 30-40 students annually during the summer. A team of three to five instructors from various civil engineering disciplines collaborated annually on the course design and delivery. Although intended to be a residential course, in the first year the course was offered fully virtually due to COVID-19. The remaining years were offered fully inperson with some adaptation for 2021 also due to the pandemic (i.e., social distancing, less group work, and no field trips). Course activities occur daily from 8:30 am to 5 pm, with a break for lunch. Students are expected to complete up to 1 hour of additional work outside of class hours in preparation for the next day's activities.

To join a course cohort, students apply and are admitted to the course through the university's summer program office. Student recruitment is completed by the civil engineering department and the university's summer programs office. The civil engineering department's efforts focus on developing a course webpage highlighting previous years' courses, reaching out to alumni, and interacting with civil engineering organizations like ASCE. The university marketing is generally broader and geared to promote all summer programs. The university advertises in various public places, including social media, billboards, and email campaigns to alumni and friends of the university.

Students enrolled in the course are generally rising high school juniors or seniors. Intervention during this time in their lives is particularly important as they are considering if they will apply to college, what they would study, and what is attractive in universities. No explicit high school class completion requirement is enforced for the course, but course developers assume students entering the class have basic Algebra and Geometry skills. Some students have previous exposure to high school engineering classes, but these classes are often focused on robotics or computer-aided drafting. Students are recommended to bring a laptop or tablet; if not, one will be loaned to them free of charge from the university for the duration of the course.

Students generally come to the course with a limited view of civil engineering. When asked to define civil engineering students in pre-course surveys, students nearly exclusively mention structural engineering domain topics like buildings and bridges with sparse references to roadways and pavements. To broaden students' perspectives, course content focuses on the breadth and depth of civil engineering. Students leave this course with knowledge of additional aspects of civil engineering beyond just structural engineering, including hydraulics, environmental, and architectural engineering, as well as a deeper understanding of more familiar buildings and bridges.

The course is designed using a backward design philosophy. As part of this process, instructors first develop course outcomes and then individual course objectives for each civil engineering discipline. From here, the course assessments and activities are developed. The methods have been adjusted over the past 4 years based on instructor and student feedback. For example, after hearing in 2020 that students were sometimes confused about how various civil engineering topics connected, starting in 2021, instructors employed day themes to help students see how various types of civil engineers address similar things. An example of these themes for 2021 is included in Table 1.

Table 1. Course structure example from 2021

Day	Topics
Day 1	Introduction, what is civil engineering
Day 2	Population Growth
Day 3	Sustainability
Day 4	Adaptability
Day 5	Project poster presentation and wrap-up

Innovative course activities are discussed briefly here so that other instructors can consider using these activities or techniques in their classrooms.

- Autonomous Vehicle Debate: students are divided into two groups to argue for and against the introduction of connected and autonomous vehicles. Students present arguments regarding the impact on safety, environment, equity, and road safety. The debate is structured in multiple rounds: opening remarks, rebuttals, and closing statements.

- Building Code Scavenger Hunt: students are tasked to identify types of loads and load combinations to get familiar with ASCE/SEI 7-22 Minimum Design Loads and Associate Criteria for Buildings and Other Structures. The students are given a fill-in-the-blank handout to find specific details in the standards.

- Universal Design and Building Accessibility: Students are tasked with exploring the first and second floors of one of the academic buildings in pairs. Students fill out a handout documenting any part of the building that is not equitable/accessible (i.e. lack of elevators, narrow door openings, difficult-to-open doors, lack of handicap restrooms). Students report their findings and discuss measures to improve the design.

- Case Study Analysis - Learning From Disasters: Students are assigned a group reading and provided a handout. The readings talk about past natural disasters, including background and remedial actions after the event. The handout asks them to describe the design process steps the engineers followed in the context of the reading presented. The steps for the engineering design process are: identify the problem, research the problem, identify possible solutions, select solutions, construct prototypes, evaluate solutions, communicate solutions, and redesign.

- Truss Bridge Mechanics: Students are assigned a picture of a truss bridge, draw one frame, and guess which members are in compression or tension. Then, they are asked to build this bridge using a bridge-building kit that includes members, connectors, and load cells. Students are provided with a handout with instructions on calibrating the load cell and determining the maximum tension and compression load.

- Aerial Mapping Technologies: Students use drones to survey an open area. They capture their pictures and later post-process them to generate a 3D model of the area with the aid of computer software. The model is generated based on predetermined features provided by the instructor. Students are provided information on field surveying and drone piloting before going to the field.

- Smashing M&Ms: Students are provided with M&Ms, pieces of paper, and s gel pad. They are asked to fill out a handout describing their experience crushing M&Ms using their fist under different conditions: (1) no protection, (2) a piece of paper, and (3) a gel pad. Students experience the effect of impact energy and how it can be related to a large scale. Students debrief at the end on their experience and how to apply it to extreme hazards.

In addition to these activities, students are assigned to groups for a week-long summative poster and presentation. Instructors generate random three- to five-person groups and then adjust the group makeup to not isolate women and minorities as able as well as split up any students who came to class already knowing each other. Past project prompts are listed in Table 2. To address these problems, students take concepts in class and are asked to extend and look beyond class concepts to address these future-oriented problems. These problems are intended to help students see that there is no one solution to engineering problems and encourage them to consider how future engineers (like them!) need to think differently than engineers of the past, all the while supporting them with tools on how to approach these problems.

Table 2. Project prompts for 2020 to 2024

Project Title	**Project Prompt**
Sustainability and resilience	Each team chooses a city, determines needs, and indicates solutions relevant to transportation, hydrology, and structural engineering aspects.
Parking lot redesign	Redesign a parking lot addressing three categories to serve the community better: (1) energy and the environment, (2) changing populations, and (3) health and safety. Discuss how these factors are addressed from the perspectives of transportation, construction, architecture, and structures.
Transportation congestion solution	Propose a solution to pedestrian and vehicle traffic congestion associated with large campus events like sporting events and graduation. Solutions should be contextualized to the local needs and use innovative technologies.
Design a habitat on the moon	Provide a design solution for a habitat on the moon considering design for extreme conditions including meteor impact, limited construction materials, limited water and food resources, and human comfort.

COURSE ASSESSMENT

This summer course's efficacy was evaluated through a comprehensive survey, employing a Likert scale to gauge student alignment with a variety of course components. This formal assessment was anonymized before the evaluation and focused on four categories: knowledge, engineering profession, motivation, and pedagogy. The questions used in each category are presented in Table 3.

Translating the Likert scale to numerical values, with 0 representing "Strongly Disagree" and 4 signifying "Strongly Agree," allowed for quantitative analysis of student perceptions over four consecutive years, from 2020 to 2023 with a sample size of 30 to 40 students each year. The mean response and error bars representing one standard deviation are shown in Figure 1 to Figure 4. Some questions were not asked in year 1 or 2 of the program and if so no bar is shown in the figure for the year.

Table 3. Assessment questions in the evaluation survey

Course components	**Questions**
Knowledge	1. The instructional materials (i.e., slides, readings, handouts, etc.) increased my knowledge and skills in the subject matter.
	2. The course was organized in a manner that helped me understand underlying concepts.
	3. This course broadened my knowledge of the study and practice of civil engineering.
Engineering profession	4. This course helped me develop professional skills (e.g., written or oral communication, reading computer literacy, teamwork, etc.).
	5. This course encouraged me to consider a career in civil engineering.
Motivation	6. I understand the relevance of the material to real-world challenges.
	7. I believe what I learned in this course is important.
Pedagogy	8. The lectures, readings, and assignments complemented each other.
	9. Assignments were reflective of the course content.
	10. Instructors clearly defined expectations for learning.
	11. Instructors fairly assessed student learning (e.g., through quizzes, homework, projects, and other graded work).

Evaluation of course knowledge growth from 2020-2023 is shown in Figure 1. The results indicate an overall highly positive response to knowledge-related questions. Particularly relevant to developing a pipeline, over half of students strongly agree with Question 3, indicating that the course broadened their understanding of the civil engineering field. With the increased knowledge of civil engineering, especially the breadth, students may, in turn, be better able to see how their knowledge and the field of civil engineering overlap.

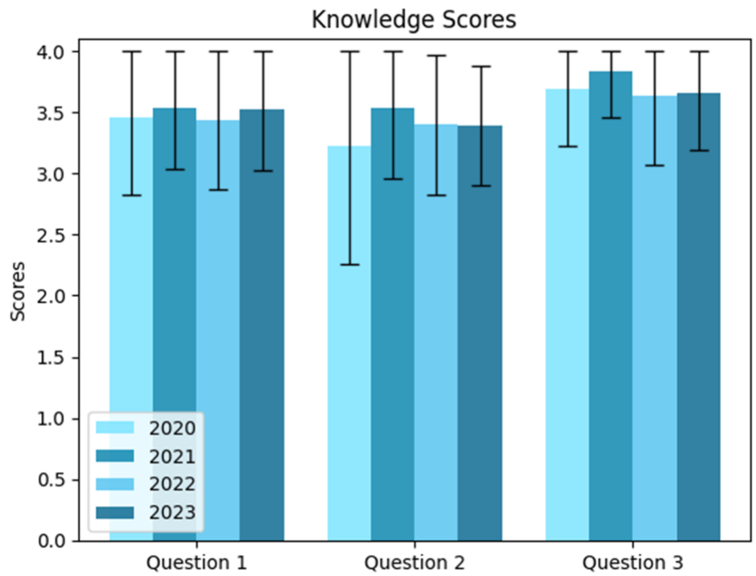

Figure 1. Knowledge scores from 2020 to 2023

Next, Figure 2 assesses students' perceptions of their professional skills and desire to pursue civil engineering as a career. Students reported similar results for developing professional skills from 2021 to 2023. Student interest in pursuing civil engineering as a career has grown marginally from 2020 to 2023. In 2023, nearly half of respondents strongly agreed that they were encouraged to consider civil engineering as a career through this course.

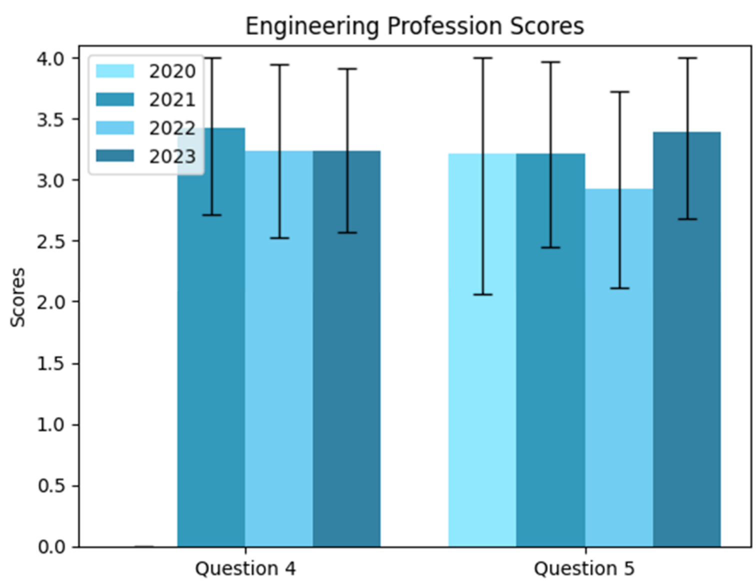

Figure 2. Engineering profession scores from 2020 to 2023

Student responses to questions related to motivation, including understanding the relevance of what they are learning (Question 6) and believing what they are learning is important (Question 7), are shown in Figure 3. Question 6 was only asked in 2022 and 2023 but showed a large drop in student agreement. The team speculates this change in student perception may be related to the project topic. In 2022, students developed solutions to a more tangible problem (traffic congestion), while in 2023, students developed solutions related to life on the moon (something they may not believe applies to their lifetimes). Similarly, there was an overall upward trend in the belief that these topics were important (Question 7), but there was a small drop in 2022.

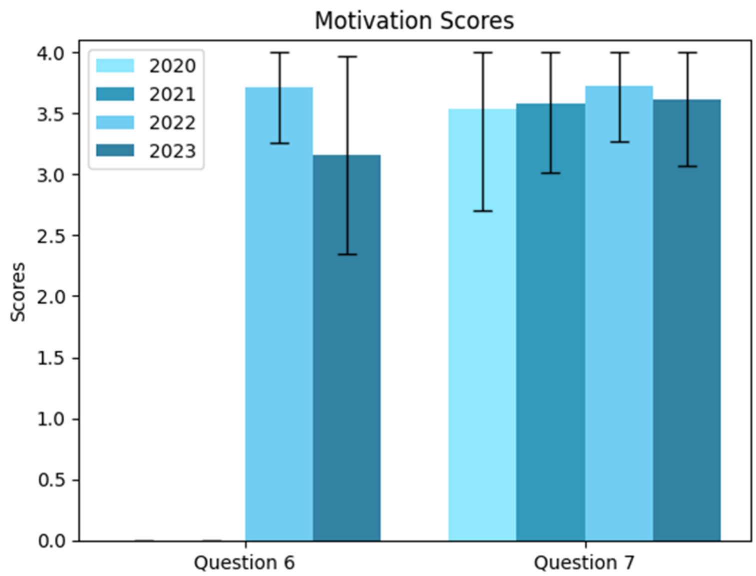

Figure 3. Motivation scores from 2020 to 2023

Finally, course pedagogy practices were assessed over the four years. Students consistently reported higher scores in 2021-2023, likely indicating that the initial growing pains of launching a new program (and COVID-19) were addressed in the following years. Continued refinement, especially in making clear expectations, is necessary. These relatively lower scores may also reflect differences between university and high school programs or between student expectations of summer programs and summer courses for credit.

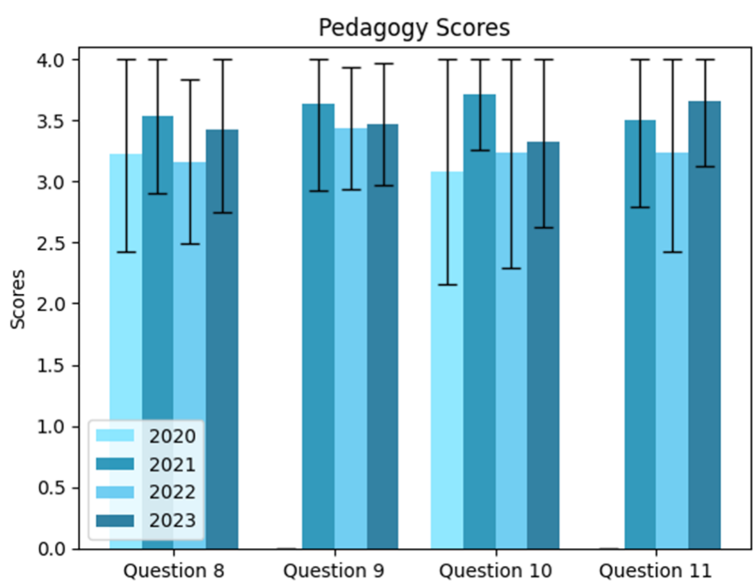

Figure 4. Pedagogy scores from 2020 to 2023

CONCLUSIONS AND FUTURE WORK

The innovative summer course has demonstrated an impact on pre-college students' perceptions and understanding of civil engineering. The assessment data from 2020 to 2023 provides evidence of the course's effectiveness in enhancing students' knowledge, skills, and interest in civil engineering as a potential career path. The sustained improvements across survey categories reflect the thoughtful design and execution of the program.

These findings are particularly significant against the backdrop of a national shortage of civil engineers and the increasing demand anticipated due to new infrastructure investments. By capturing the imagination of young minds and equipping them with a foundational understanding of civil engineering, the summer course is not just educating future students; it is contributing to the development of the workforce that will shape tomorrow's infrastructure.

Past students have gone on to enroll in civil engineering as well as other engineering programs in college. While further research and time is needed to assess post-graduation outcomes and the types of engineering careers these students ultimately enter, the initial indications are promising. These findings support the replication and adaptation of this model across other institutions, suggesting that such educational interventions can play a pivotal role in cultivating a capable engineering workforce.

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