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Impact of a Sustainability-Focused Programming Intervention on Civil Engineering Student Self-Efficacy and Interest

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Abstract

This paper examines the impact of incorporating a service-learning project into a computer programming course on civil engineering student's self-efficacy and interest in both programming and the field of civil engineering. The course was redesigned in collaboration with Santa Clara University's Center for Sustainability to include a service-learning project that connects sustainability with computer programming skills. The service-learning project addressed a campus-wide challenge related to waste management, aligning with the University's goal of reducing waste sent to the landfill. It began with an information session presented by the Center for Sustainability, which introduced the concept of sustainability as the interdependence of social, economic and environmental systems. This was followed by a waste characterization event where students sorted and weighed misclassified waste. The main task required students to use data analysis and computer programming to address a specific research question about campus waste. The final deliverable included a memo to the Center for Sustainability presenting the research question, data analysis and actionable recommendations to reduce waste entering the landfill.

Data for this study comes from pre- and post- course surveys that gather both quantitative and qualitative insights. A pilot of the course was offered in Fall 2023, generating initial findings, and was offered again in Winter 2025, with an enrollment of 48 students. Where possible, data will be disaggregated to explore whether the project had a greater impact on the self-efficacy and interest of underrepresented students more than traditional civil engineering students. Drawing on Bielefeldt's [1] findings, it is expected that incorporating service learning into engineering courses will increase self-efficacy and retention more for underrepresented groups.

1. Motivation and Background

Computer programming, including algorithm creation and numerical methods, is an essential skill for civil engineering students [2] but can be a roadblock for many students. The course is often seen as a requirement and not immediately relevant to students' future as civil engineers. Based on personal experience of the author, it is not until students graduate and attend graduate school and begin to apply the coding skills to an area of interest that some students understand the relevance. To meet the needs of the civil engineering workforce, improving computer programming skills is essential. To accomplish this, as well as meet the needs of an increasingly diverse student population, an innovative approach is needed in teaching computer programming skills to civil engineering students. Service-learning and situated learning provide the framework for a new project in a Computer Methods for Civil Engineering course.

Service learning is a type of experiential learning that combines community service with classroom learning, including preparation and reflection [3]. Service learning in engineering enhances disciplinary knowledge [4], [5], [6] and improves professional and personal skills, including teamwork, communication, leadership and ethical awareness [7]. Service learning also helps students develop a sense of social responsibility [8] and reiterates the role of engineering as a service profession, especially for underrepresented students [6], [9]. As the edited volume by Tseng [10] summarizes, there are a number of examples of service-learning design projects in engineering courses. The service-learning project in this study, however, emphasizes analysis rather than design as a way to increase student interest in the topic of computer programming and stay motivated to learn an important but threshold concept with the goal of increasing retention in the discipline.

An additional difference of this particular service-learning project is the location and context of the service-learning component. Rather than engaging with an off-campus partner, the project partners with the on-campus Center for Sustainability on a campus wide sustainability goal. The on-campus accessibility helps to overcome at least one roadblock associated with community-based service-learning opportunities, in particular the formation of strong partnerships [1]. The Center for Sustainability at Santa Clara University actively seeks opportunities to partner with faculty to engage students in applied learning opportunities that address campus-based sustainability challenges. Providing a service-learning project on campus also means the students are participating in and contributing to the solution of a real problem in a community where they already belong. The new service-learning project is an example of learning through situated learning, a theory of instruction that states that learning and knowledge building are connected to the real-world situation where learning occurs [11], [12], [13]. The meaningful project allows students to learn while doing with a community of classmates [11] an essential component of situated learning.

This research seeks to answer the following question related to students' persistence and retention in Civil Engineering: How does a service-learning project on campus influence students perceived self-efficacy, interest in programming and the perceived utility of programming in civil engineering careers? The hypothesis is the project, focused on a sustainability problem on campus, will improve self-efficacy and interest in programming, especially for underrepresented students. To test this, a multistep project was introduced into a required sophomore level course for civil engineers. The impact of the project is assessed used mixed method analysis using data from surveys and student reflections.

2. Methods

The Course

One section of Computer Applications for Civil Engineers is offered each year and is a required course for sophomore Civil Engineering Students at Santa Clara University, a midsize, primarily undergraduate private university. The course introduces civil engineering students to computer programming through MATLAB with an emphasis on developing algorithms for complex problems. Prior to the 24/25 academic year, the course was offered in the fall quarter but was moved to winter quarter beginning in winter 2025. A pilot of the project used for project validity but with minimal data collection was offered in fall 2023 and a second version of the project with a detailed data collection plan was implemented during the winter 2025 quarter. The fall 2023 course had 33 students and the winter 2025 course had 48 students. The 10-week course meets twice per week for 100 minutes and beginning in winter 2025 also has a lab component, taught by a separate instructor. Before the service-learning project, the course contained 3 open ended but shorter projects and the new service-learning project, along with in class quizzes replaced those shorter projects.

Service-Learning Project

The service-learning project was inspired by a similar project at Portland State University which used data analysis of litter collection on campus in a similar course [14]. However, for this project, the additional stakeholder of the Center for Sustainability from Santa Clara University was brought in to both offer additional context for the project and problem and to receive the final deliverable. The project is designed to address 3 of the course learning outcomes: (1) Analyze large data sets in MATLAB, (2) Communicate data effectively to a target audience, and (3) Use data and computer coding to recommend policies to meet university sustainability goals around resource use and consumption. The third course learning outcome was added after the partnership with the Center for Sustainability. Additional purposes of the project include introducing students to the Center for Sustainability, the three systems of sustainability and the concept of circular economy. The project includes 8 activities or deliverables summarized in Table 1.

Table 1. Summary of activities and deliverables for the Service-Learning Project in Computer Methods for Civil Engineers. Bolded items provide data for this study.

Activity	Description	Purpose	Data
1	**Introduction Survey**	**Collect pre course survey results and student goals for the course.**	**Quantitative Qualitative**
2	Center for Sustainability Introduction	Provide a common definition and framework of sustainability, sustainability at XXX and the University's goals related to waste.	NA
3	Reflection	Reflect on understanding of sustainability before and after the presentation from Center for Sustainability	**Qualitative**
4	Waste Characterization	Sort waste in landfill bins from Engineering Building into compost/recycling/waste and see how much waste is sorted incorrectly	NA
5	Write potential research questions and research plan	From your experience at the waste characterization, write research questions and develop a plan to answer the questions using data available.	NA
6	MATLAB Code	Use MATLAB and data to answer your research question. Includes practice in loading data into MATLAB, using built in MATLAB functions and creating code to analyze and visualize data.	Quantitative data
7	Communication to Center for Sustainability	Communicate research, conclusions, and recommendation to a target audience.	Quantitative Qualitative
8	**Final Survey and Reflection**	**Collect post course survey results, reflection on attainment of student goals**	**Quantitative Qualitative**

The service-learning partnership is introduced in Activity 2 when a representative from the Center for Sustainability comes to the class and leads a discussion with the class on sustainability, including defining sustainability and a detailed history of sustainability on Santa Clara University (SCU) campus. The Center for Sustainability facilitates the implementation of SCU's Sustainability Strategic Action plan with goals related to waste reduction, in particular the reduction of waste that goes to the landfill. In the lesson from the Center for Sustainability, the students learn about the circular economy initiatives the Center for Sustainability has in place to promote reuse and reduce the waste ending up in landfills, including a Buy Nothing group and a campus free store. The campus also has a composting program and a robust single-stream recycling program. A few weeks after the introduction to the Center for Sustainability, the students participate in a waste characterization event during class time. In the waste characterization, students wear PPE including long pants, close toed shoes, gloves, goggles and lab coats and sort through the waste that was thrown away in the 'Landfill' bins from the Engineering building. The waste is then sorted into categories: true landfill waste, compostable material, recyclable material and items that could have been saved and donated to the free store. Photos from the Fall 2023 waste characterization are provided in Figure 1.

Figure 1. Waste characterization event during Fall 2023 showing students sorting through waste bags.

After the waste characterization, the data analysis portion of the project begins. In addition to the data from their waste characterization, students are provided with additional data from the Center for Sustainability, including detailed data on all waste characterizations done on campus since 2005 as well as data on overall waste trends since 2005. Students analyze diversion and contamination rates. Using their experience with the waste characterization as well as the data, students draft possible research questions. Students are encouraged to be creative about their research question and relate it to their own interests and experience with the circular economy. The instructor guides them to pick questions that can be answered using the technical content of the course, meaning the data set should be robust enough that it can be analyzed and visualized using MATLAB, thus ensuring that the service-learning project is still advancing the learning outcomes of the course and program.

After the students have working MATLAB code, the final deliverable is a communication to the Center for Sustainability that includes their analysis as well as recommendations. Student can choose between a technical memo or an infographic as the final communication. The final step in the project is a final reflection and survey.

Data Collection and Analysis

The data for this research includes both qualitative and quantitative data collected throughout the quarter. The quantitative data that can be used to directly answer the research question comes from a self-efficacy survey administered at the beginning and end of the course. The self-efficacy questions are adapted from the Engineering Skills Assessment (ESA) developed by Maloney et al [15] and used by Dent et al [5]. The assessment asks students to provide a rank for a list of skills on how important they think that skills is for engineers and then give themselves a rating on how well they have developed that skill. In the original Skills Assessment created by Maloney and her team [15], the skills are categorized as job related, interpersonal and life skills. For the current study, a 4th category was added with additional skills directly related to the course learning outcomes related to computer programming. At the end of the quarter, a written response question is asked for each group of skills asking why changes took place and if the project had an impact on their skill development. A copy of the survey is provided in Appendix A. Because of the expected non-normal nature of this data, a Wilcoxon signed-rank test will be performed to compare the pre and post survey data from the ESA. This will allow for the determination of significant changes in any of the data. Differences based on demographic data will be compared using Mann-Whitney U test. Qualitative data included in this study include additional questions in the final survey. Analysis of this data will include thematic analysis coding to identify key themes [16] and any differences based on gender or first-generation status.

For all data collection, only students who consented to their results being used included in the study are included in data analysis.

4. Results

The results from the Engineering Skills Assessment (ESA) and post-course reflection questions indicate improvements in students' confidence and perceived importance of skills across all categories. Notably, course-related skills saw the greatest increase. Disaggregated analysis reveals nuanced differences by gender but not by first-generation status.

Student Demographics

The number of students included in the study is 35, 75% of the total class. Of those included, 18 identify as male and 17 as female. There are 10 first generation students included in the study. All students are declared as civil engineering majors at the start of the winter quarter. Table 2 summarizes the demographic distribution.

Table 2. Distribution of Students by Gender and First-Generation status (N = 35)

	First Generation	**Not First Generation**	**Total**
Female	5	12	17
Male	5	13	18
Total	10	25	35

Engineering Skills Assessment

For a comprehensive look at changes in ESA values, the data sets were analyzed as broad groups. Rather than looking at the ranking of each skill, they are grouped into interpersonal, technical, soft and course skills. The average in each category for each student was determined and compared, and the results for both the beginning and end of the course are shown in Figure 2. At the end of the course, all categories had an increase in the average rating compared to the beginning of the course. From the beginning to the end of the course, the change in student rating of the importance of interpersonal skills was highly significant ($p < 0.01$) and course-related and technical skills were significant ($p < 0.05$). Similarly, the students' confidence in all areas increased with confidence in course related and technical topics being highly significant ($p < 0.01$) and interpersonal topics being significant ($p < 0.05$). When looking closely at each category, student confidence in course related skills had the greatest changes. Within the broad category of course related skills, confidence in algorithm creation increased from an average of 1.78 to 3.69 on a scale from 1 to 5. Confidence in computer programming and debugging also increased by more than 1.5 from the beginning to the end of the course.

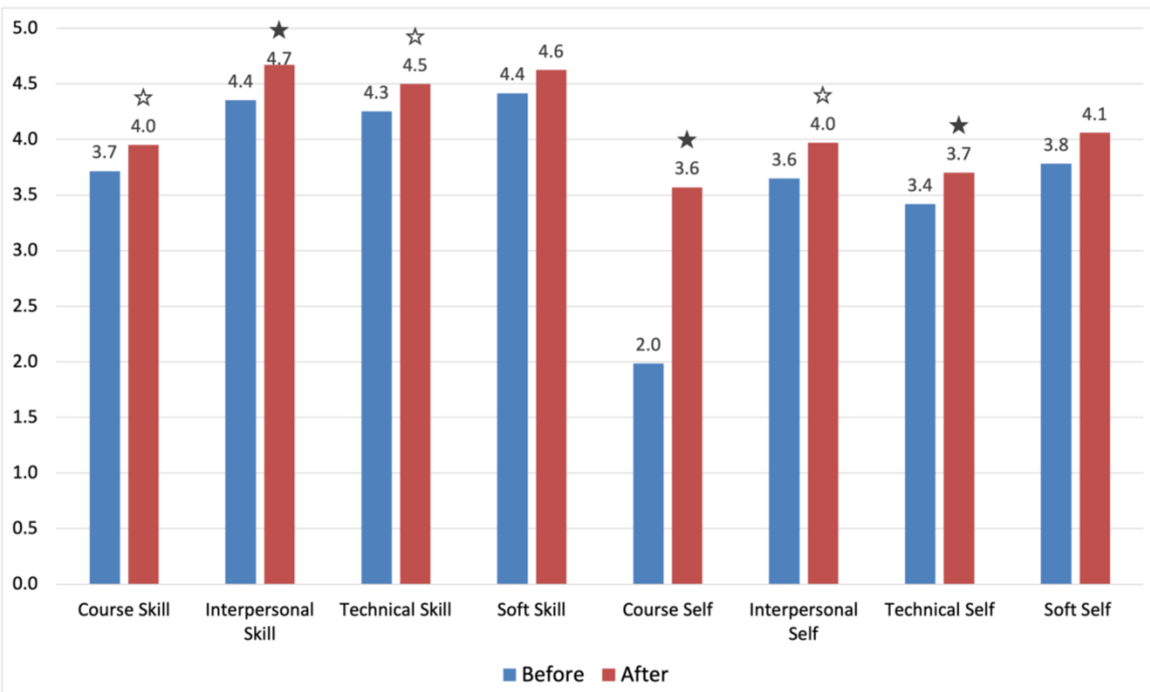

Figure 2. Comparison of the average rating of grouped skills before and after the course. Bold categories (course and technical skill and course self) have a statistically significant change from before to after the course.

Comparisons were made based on gender and first-generation status to see if the before and after course changes differed by group. As seen in Figure 3, both male and female students demonstrated improvements across all broad skill and confidence categories after the course. However, female students exhibited significantly greater gains in their confidence in course-related skills ($p = 0.0063$) and marginally greater improvements in the importance of both interpersonal skills and course-related skills, suggesting the course may have had a particularly strong impact on female students' self-efficacy and professional skill development.

There was no significant difference between first-generation and continuing-generation students between categories or changes from the beginning to the end of the course. Similar to the entire data set, both groups increased their belief that technical and course-related skills are important to their career and increased their confidence in course-related skills.

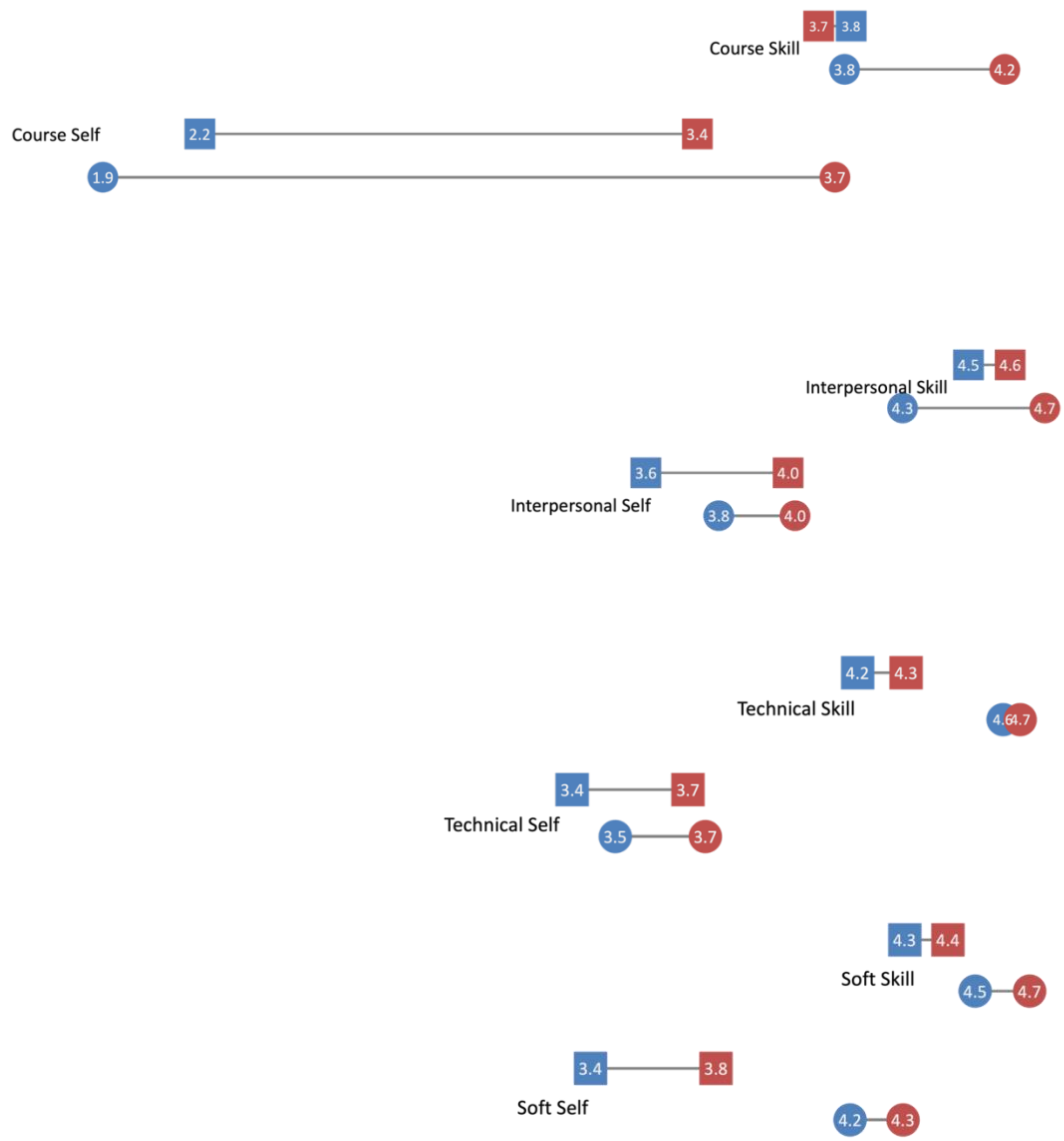

Figure 3. Comparison of student ratings of the importance of skills in their career and their perceived ability in that skill before (blue) and after (red) the course. The figure includes differentiation for female (circles) and male (squares) students.

Reflections

When the engineering skills assessment was administered at the end of the course, additional open-ended questions asked students how, if at all, the project helped students to develop confidence in the skill sets identified in the survey. Students answered for three broad categories: interpersonal skills, technical skills and course related skills. For each question, the majority of the 35 students in the study said that the project did help with their confidence in those skills. The greatest percentage was for course related skills and the lowest for interpersonal skills. Table 3 summarizes this data for each question (N = 35).

Table 3. Summary of number of students who indicated that the project or course improved a particular skill set

Question	Number of Positive Responses (out of 35)
How, if at all, did the project and help to improve your **interpersonal skills** - including communication (written and verbal), ability to work in a group or team, and leadership?	22
How, if at all, did the project and course help to improve your confidence in **job related skills** - including math and science skills, creativity, problem solving, technical skills and analytical skills?	26
How, if at all, did the project help to improve your understanding and confidence in algorithm creation, writing and using computer programs, debugging computer programs and communicating using figures (**course related skills**)?	28

Thematic analysis of the responses helped to identify common themes across skill categories and explore differences based on gender and first-generation status. For interpersonal skills, common themes included communication, teamwork, seeking help, leadership, and patience. For job-related skills, students most frequently mentioned problem solving, technical and analytical skills, confidence growth, and creativity. In course-related responses, prominent themes included programming and algorithm development, debugging, communicating through figures, and learning through trial-and-error. The sections that follow summarize how these themes varied by student identity.

<u>Gender based differences in Responses</u>

For the 22 students who reported growth in interpersonal skills, more than half were female (15). The most frequently mentioned theme in this category was communication, cited by 15 female and 10 male students. Some students mentioned communication even if they did not report overall growth in the skill. Teamwork and asking for help were mentioned with similar frequency for male and female students, while leadership and patience were only mentioned by female students.

One female student reflected, *"During the project I had to communicate with those around me and we had to work as a team to delegate tasks to each individual [during the waste characterization]."* A male student answered this question, *"The project helped me develop new ways to ask for help when starting a project."* (Male student)

Twenty-six students reported growth in job-related skills. Problem solving and technical skills were cited often by both genders, but 10 out of 17 female students versus 6 of 18 male students were more likely to report increased confidence overall. A female student noted "*The project and course have helped me to improve my confidence in job-related skills in all aspects. […] Also, my technical skills have since improved as I feel that we did a lot of data analysis, technical writing, and others that pertain to that skill*". Only male students (3 out of 18) mentioned increase in math and science related confidence. For example, one male answered *"It strengthened my math and coding skills by interpreting statistics and data on contamination rates and making sense of large datasets."*

Course-related skills were the most commonly cited area of confidence growth, with 28 out of 35 students responding that the course and project improved their skills. For example, one student stated Both female and male students described improvements in algorithm development and debugging. However, female students were more likely to specifically mention programming 7 out of 17 female students versus 2 out of 18 male students). One female student responded ""*The project helped me improve my confidence in my ability to write computer programs and debug as even though there were lab codes…, there was no right way to code a solution to my problem.*"

<u>First-Generation Status Differences in Responses</u>
Ten students identified as first-generation. Of these, 6 reported growth in interpersonal skills, and all 10 in job-related and course-based skills from the project and course. For interpersonal skills, compared to continuing generation peers, first generation students more frequently mentioned teamwork (4 of 10 first generation students vs 7 of 25 continuing generation students) and help-seeking (3 of 10 vs 4 of 25) while leadership was mentioned exclusively by continuing generation students.

One first generation student shared, *"It helped me be understanding where I still struggled in and where I had to ask for help. I had to learn to communicate better with my classmates and professors,"* reflecting the growth of support-seeking. Another first-generation student wrote "*I felt like doing the waste characterization event allowed me to collaborate with. my peers regarding proper waste sorting"* when discussing teamwork and collaboration.

When asked about job related skills, six first-generations students cited an increase in confidence in creativity versus 10 out of 25 continuing generation students. As one first generation student cited, *"I feel more confident, specifically in problem-solving, creativity and analytical skills… The project challenged me to think more outside of the box*". In contrast, only continuing generation students specifically mentioned an increase in confidence in math and science.

In course-related reflections, first-gen students were slightly more likely to describe learning through trial and error and communicating through figures, while programming confidence, debugging, and algorithm development were noted across both groups.

These results suggest that situated, real-world projects may particularly benefit female students' confidence in technical and programming skills, even in traditionally low-efficacy domains

Limitations

This study has several limitations that should be considered when interpreting the findings. First, there was no control group: the service-learning project was implemented in the only available section of the course, making it impossible to distinguish whether observed improvements were due to the intervention or the course itself. Second, the sample size was modest (N = 35), and subgroup analyses (e.g., intersectional analyses of gender and first-generation status) were limited by small sample sizes. Third, the study relied on self-reported confidence and reflection rather than performance-based assessments of skills, which introduces potential bias.

Finally, the dramatic enrollment increase between Fall 2023 (33 students) and Winter 2025 (48 students) may have influenced outcomes, particularly in terms of instructor feedback and student-instructor interaction. Future iterations of the course will include multiple sections, which may introduce variability in delivery and outcomes across instructors.

Future Work

Future work will focus on four key areas. First, additional data analysis will be conducted on student responses regarding their understanding of sustainability before and after the project. This will help determine how the intervention may have influenced students' environmental awareness and attitudes. Second, a mechanism to allow student projects to be implemented by the Center for Sustainability is under development. Implementation would provide an opportunity to assess whether real-world impact reinforces learning outcomes, particularly confidence and civic engagement. Third, a longitudinal study is planned to track students into upper-division and capstone courses to assess whether those who participated in the course are more likely to use MATLAB or pursue sustainability-oriented projects. Finally, future studies will explore replicating this approach in other programming-heavy courses across engineering disciplines to assess generalizability.

5. Conclusions

A service-learning project partnered with the University's Center for Sustainability was introduced into a required sophomore level computer programming for civil engineers course with the goal of increasing interest and self-efficacy in computer programming skills. The intervention resulted in statistically significant increases in student confidence across all skill categories, with the greatest gains in course-related skills such as programming and debugging. Female students demonstrated particularly strong gains in technical and programming confidence, suggesting this type of applied, situated learning project may help reduce gender-based gaps in self-efficacy.

Contrary to prior research, first-generation students did not show significantly greater gains than their continuing-generation peers, though qualitative data indicate positive impacts on teamwork and help-seeking behaviors.

This study contributes to the growing body of research on integrating civic engagement and sustainability into core engineering coursework. By aligning technical learning with real-world problems and professional identity formation, the course helped foster both skill development and student engagement. Future work will explore implementation of student recommendations, longitudinal impacts on learning, and scalability across disciplines.

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Appendix A – Engineering Skills Assessment

Civil Engineering Skills Assessment

Rank each of the skills listed below in order of how important you believe they are for a civil engineer to have (1 being least important and 5 being most important). Then, on a scale of 1-5, how well developed you are in that skill (1 being not developed at all, 5 being fully developed)

	Importance for Civil Engineering	Self-Development Score
Interpersonal Skills		
Communication		
Ability to work in a team/group		
Leadership and management		
Leadership and management		
Technical skills		
Math and science knowledge *(not including computer skills)*		
Technical skills and knowledge		
Analytical skills		
Problem Solving		
Soft Skills		
Creativity		
Time management skills (including punctuality)		
Orderliness and organization		
Attention to detail		
The following skills are derived from the course Syllabus		
Algorithm creation		
Writing and using computer programs		
Communicating data using tables and figures		
Debugging computer programs		