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CASE STUDY: Project-based integration of societal context with engineering communication and computational thinking in an upper-level civil and environmental engineering course

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1. Introduction

We present a project-based approach to integrate technical analysis within societal context, computation, and effective communication, in an upper-level civil and environmental engineering course. These skills are essential for engineering education to meet the evolving demands of engineering in an increasingly interconnected world [1]. Our approach resembles the "teaching factory" model [1], inspired by the medical teaching hospital, where engineering students engage in real-world processes under expert supervision, where technical training is conscious of its societal impact and the technical results are appropriately communicated to diverse stakeholder audiences. Unlike traditional teaching in engineering, emphasis is given on writing. Despite its critical role in professional communication and assessment, writing practice in engineering is often marginalized and outsourced to external units, assessed summatively without formative practice, and treated as a peripheral skill [2]. There is need for systemic changes in engineering curricula to make writing practices more visible, developmental, and integral to engineering education. Here, we present a step in that direction through project-based learning. Project-based learning provides a framework to integrate the fostering of computational and communication skills in a socially conscious context for civil engineers. Further, the integration of computational tools into project-based learning has been shown to significantly enhance student engagement and learning outcomes in engineering courses [3].

The project we present in this case study aims to foster critical thinking and professional skills. It is assigned in a 3rd year undergraduate civil and environmental engineering course on energy and the environment, with three goals: 1) Increase students' awareness and understanding of engineering in a societal context; 2) Strengthen students' problem solving, data analysis and visualization skills, and confidence using computational tools; and 3) Develop students' ability to communicate their expertise to a range of audiences.

2. Course and project description

The 3rd year undergraduate course where the project is assigned has the following learning objectives:

- Understanding engineering decisions within a certain societal context.
- Understanding different energy systems and sources with their advantages and disadvantages.
- Assessing the current state of energy in the global environment, including potential ways for addressing challenges with the current energy systems.
- Articulating research questions and becoming competent in collecting and analyzing data to draw conclusions on impacts from different energy systems.
- Improving technical writing skills and communication of results and conclusions to different audiences.

Aligned with the learning outcomes, a project is assigned in multiple parts that students work on throughout a 15-week semester. Throughout the course, learning modules are covered that support the three goals of the project (Figure 1) and the associated deliverables (Figure 2).

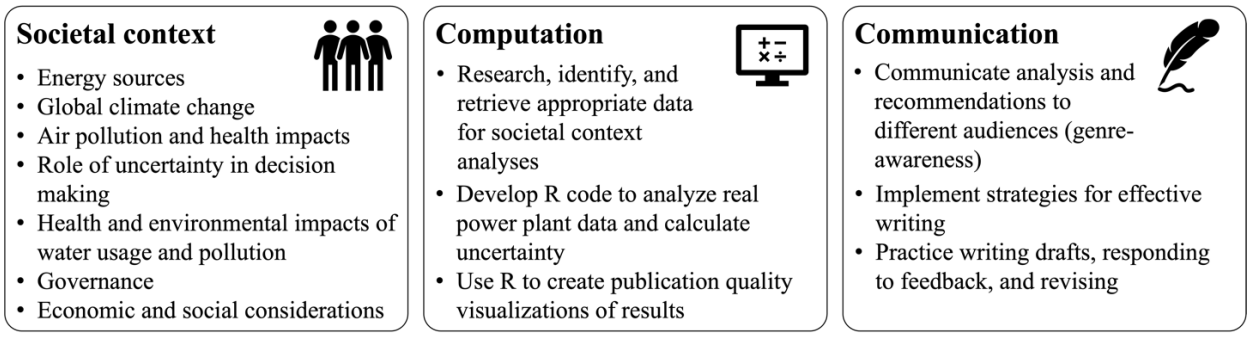

Figure 1. Course modules in support of project stages and goals.

For this project, each student is randomly assigned an active U.S. coal-fired power plant and is tasked with making a recommendation on whether to retire the plant within the next 5 years. Students are expected to use four criteria: 1) CO_2 and air pollution emissions from the power plant; 2) Impacts on water, including water consumption and withdrawal, environmental and societal impacts on water sources, and wastewater; 3) Impacts on human health and risk; and 4) Economic, consumer, and social considerations. The analysis is expected to be a mix of quantitative, semi-quantitative, and qualitative factors that students communicate through a technical report intended for a supervisor or someone with a similar technical background.

2.1 Goal 1 - Engineering in a societal context

Following the topics in the course schedule, students are required to research and assess how their selected power plant affects surrounding communities, including the dispersion of air pollutants; the impact to water sources through withdrawal, consumption, and waste; the impact on human health caused by pollution and occupational hazards; and other economic, consumer, and social considerations such as the role the power plant has on jobs provided, community services, and infrastructure. Quantitative assessment of the socioeconomic factors is beyond the scope of this project, but students are expected to consider and research each of these components semi-quantitatively or qualitatively to support their recommendation about whether to retire the power plant in the next 5 years. In the policy memo and op-ed assignments (see Figure 2), students must further explain and justify their recommendation from the perspective of what is important to the intended audiences of those documents, which includes local "decision-makers" and the general population for the area around their power plant, respectively.

2.2 Goal 2 - Computation for data analysis and visualization

To calculate the carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur oxides (SO_x), and fine particulate matter ($PM_{2.5}$) emissions from their power plant, students need to find and collate data from several different sources to understand the type of coal burned by their plant, the firing configuration and associated emission factors, as well as any emission reduction technologies the plant has installed and their age. This information is available across different government databases, including the EPA CAMPD facility attributes dataset [4], EPA AP-42 [5], and EIA-

860 [6]. To help students identify the necessary parameters for their assigned power plant, we provided an example in the form of a completed worksheet, demonstrating how the values were obtained for an example power plant.

Students are required to use the R [7] programming language to calculate and visualize CO_2, NO_x, SO_x, and $PM_{2.5}$ emissions from their power plant using the plant's monthly coal consumption over the last 20 years reported in EIA-923 [8]. This data is downloaded as a JavaScript Object Notation (JSON) file through EIA's open data Application Programming Interface (API) [9].

Integration of coding in this course is part of a department-wide effort to integrate coding throughout the curriculum. Thus, students have been previously introduced to basic R in a 2nd year pre-requisite course where they learn calling R functions and packages including the data manipulation package *data.table* [10]. We build on this background by working more in depth with the *data.table* package to reorganize as needed the downloaded EIA power plant data. In addition, we introduce graphics package *ggplot2* [11] for creating publication-quality visualizations. Students also write their own functions in R to calculate the power plant emissions. To prepare students for these tasks, two class sessions are reserved for introducing students to the EIA open data API, loading an example power plant dataset into R, working with *data.table*, *ggplot2*, and writing functions in R. During these classes, students work through guided R worksheets in PrairieLearn [12], a learning management platform that allows students to check their code using an autograder. The students have unlimited attempts to test their codes with no penalty.

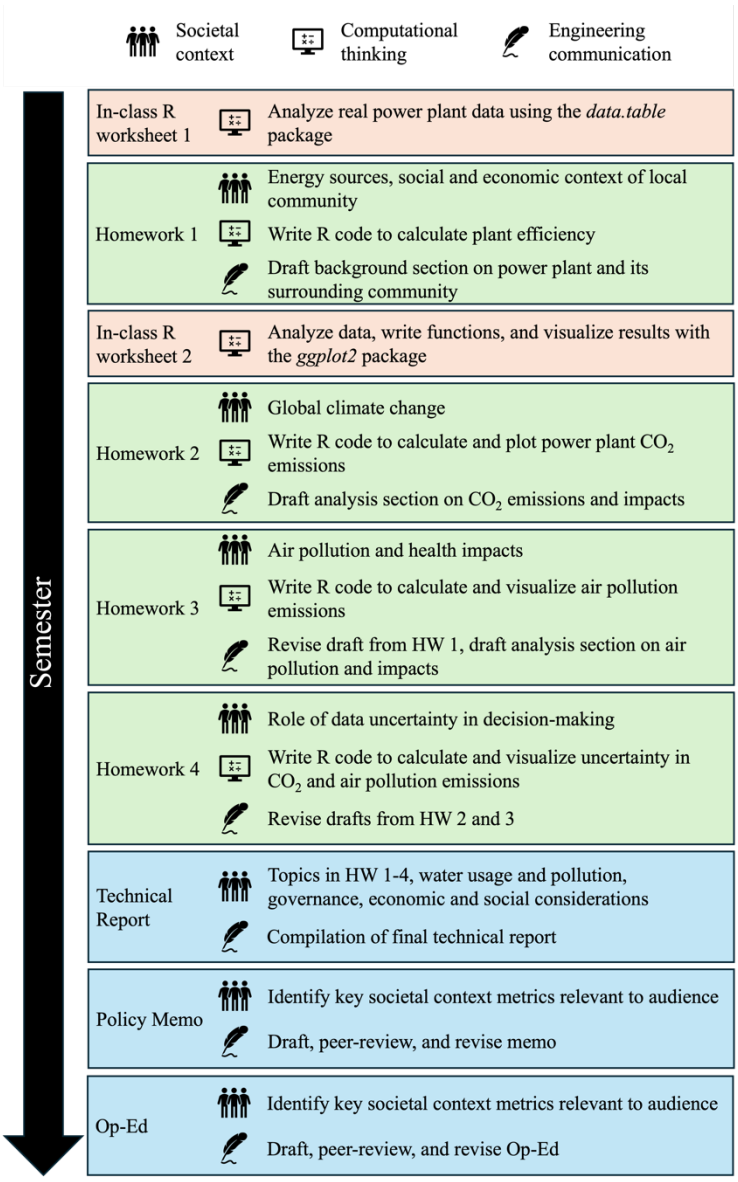

Figure 2. Overview of project intermediate (in-class: orange, homework: green) and final deliverables (blue).

Between the in-class practice and the intermediate project submissions, there are six coding assignments working with power plant data, leading up to the technical report. The initial practice assignments are designed to provide substantial guidance and example code. As the

assignments progress, less guidance and example code are provided so that students build upon what they learned in the previous assignments. By the final assignment, the students produce the results and figures for the CO_2, NO_x, SO_x, and $PM_{2.5}$ emissions over the past 20 years that form the basis for completing their technical report.

2.3 Goal 3 - Engineering communication

This project has three written deliverables: the technical report, the policy memo, and the Op-Ed. With these three assignments, we focus on both genre-awareness and strategies for effective writing.

Genre-awareness

For each of the three assignments, the students are asked to communicate the same information to three different audiences. The intended audience for the technical report is a supervisor or someone who has a similar technical background, so technical details and language are expected. The policy memo and Op-Ed, are intended for audiences in the public sphere who are unlikely to have the same technical background. With these three assignments, students are required to consider and practice how they can successfully and clearly communicate their work, including why a specific audience should care about what they are communicating, while providing enough information to support their recommendation without overwhelming the audience with technical jargon. The writing components of the project were based on the material from Susan Conrad's Civil Engineering Writing Project [13]. Resources for writing a policy memo and Op-Ed [14-17] and real-world examples [17-18] are provided to students with each assignment description and are also discussed in class.

Effective writing strategies, feedback, and revision

Emphasis was given on the lessons on accurate and precise language, simple sentence structure, and information flow. In the four homework assignments leading up to the technical report, students are asked to either write a draft section for the report and/or revise a previous draft based on instructor feedback. With each draft section, students were also asked to select an excerpt from their draft that showcased at least one of the techniques from the Civil Engineering Writing Project [13] that were covered in class. When revising their drafts, students were asked to provide a statement describing how they addressed the feedback received on their draft. The purpose of these statements is to encourage students to reflect and intentionally consider how they can implement good writing practices.

For both the policy memo and Op-Ed assignments, students are assigned to peer review two of their classmates' drafts. For each peer review, students complete a worksheet that guides them through key areas of focus in the drafts. This completed worksheet and a copy of the draft with their comments are then returned to the original student who uses this feedback from their peers to revise their draft before submitting a final version.

3. Student feedback

The project has been assigned twice, in the Fall 2023 and Fall 2024 semesters. We surveyed students in the beginning and the end of each semester to obtain student feedback. Due to space limitations, we have chosen to include here responses to the survey questions that are most relevant to the project goals, obtained at the end of the Fall 2024 semester (Figure 3). Based on

these surveys, almost all responders felt the class improved their understanding of the role of civil and environmental engineers in the broader societal context (Q1: 23 of 24 and Q2: 22 of 23 responders) and reported feeling moderately to extremely confident in communicating technical information to different audiences (24 of 24 responders) after completing the course. Regarding computational thinking, 18 of 25 survey responders reported at least moderate confidence in their ability to use coding to analyze data and solve problems. Further, 16 of 25 responders reported that the assignments in this course at least moderately increased their understanding of how coding can be used in civil engineering applications. Overall, the survey responses indicate higher confidence levels at the end of the semester toward all three goals we set for the project. Further, based on project and course grades, students have also demonstrated competency in these three areas.

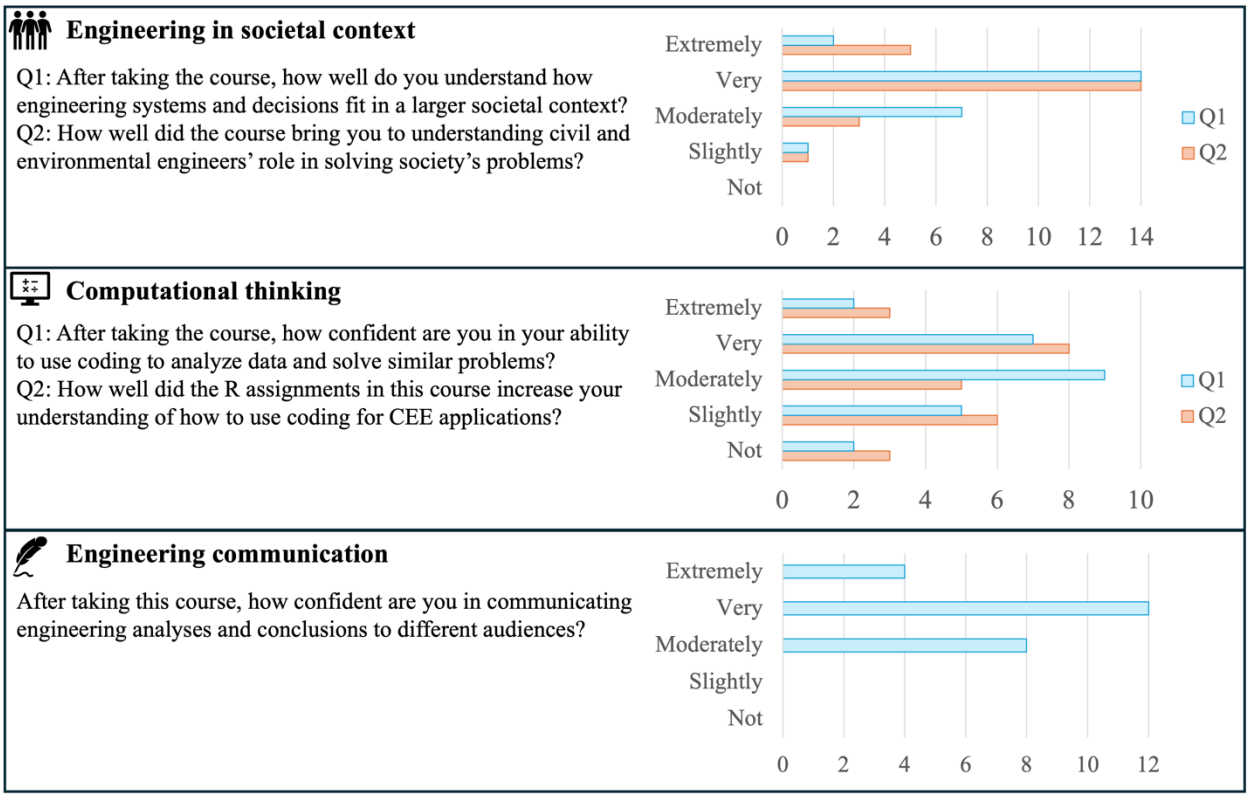

Figure 3. Fall 2024 survey results: student self-assessments regarding understanding of engineering in a societal context, computational thinking, and engineering communication (25 responses, 50% response rate).

4. Conclusion

It is accepted in the community that engineering curricula need to undergo a cultural change to prepare future engineers for a world that advances rapidly technologically with increasing complexity. In this case study, we present our project-based approach for teaching civil and environmental engineering students engineering in its societal context, while integrating computation for problem solving and writing as an essential component of the engineering educational experience. Implementation of our approach faced challenges, specifically overcoming student resistance to coding (common among students in non-computer science

disciplines [19]), and weak writing skills. To address these challenges, we followed a stepwise approach of continuous feedback and reinforcement. The student feedback indicates changing culture among students, feeling more at ease with assignments that involve solving complex problems, for which they need to be proactive and persistent problem-solvers. At the same time, assignments like this project offered throughout the civil engineering curriculum normalize coding and writing, both of which are of crucial importance for preparing future civil engineering professionals.

Acknowledgments

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