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Enhancing undergraduate students' sensing and data-informed decision-making through a smart cities project

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Abstract

Smart cities promise the ability to use data to inform city planning, resource allocation, and so much more. To do so, they require capturing, processing, and interpreting data. Considerable design work is required to ensure that data captured within smart cities can actually be used to inform decisions. For smart cities and the sensed infrastructure they comprise to be as widely adopted, as current interest suggests they will be, future engineers will need to be familiar with both the design and data aspects of smart cities. Today's engineering students will be those future engineers.

Our junior-level Civil and Environmental Engineering (CEE) project course has typically included a project involving sensing and data analysis. This year, for the first time, we deployed a project that used smart cities as the context for a project requiring full-scale design, sensing, data analysis, and decision-making amid uncertainty. Importantly, while many smart cities technologies are privacy invasive, our project was done using technology that is not privacy invasive. We assessed whether the project achieved the content and skill-oriented objectives by surveying students quantitatively and qualitatively.

Our quantitative and qualitative data suggest that students achieved many of these objectives. Notably, student perception data suggest increases in: their appreciation for coding, sensing, and data analysis for CEE; their ability to integrate sensing and data-informed decision making; and their understanding of the potential impact of smart cities. The qualitative student comments align with our quantitative data.

Smart cities provide much promise for future urban environments. To capitalize on those promises, engineers will have to gain new competencies in design, sensing, and data-informed decision making. Our junior-level smart cities project offers some ideas for how to get there.

Introduction

Smart cities promise the ability to use data to inform city planning, resource allocation, and numerous other aspects of urban environments (Albino et al., 2015; Angelidou, 2015). To do so, they require capturing, processing, and interpreting data. Considerable design work is required to ensure that data captured within smart cities can be used to inform decisions (Fujimoto et al., 2020; Heo et al., 2014). With its interest in tracking people and capturing information regarding uses of public infrastructure, smart cities initiatives can be privacy invasive (Akhter et al., 2019). Smart cities have long been touted as the future (Batty et al., 2012; Sánchez-Corcuera et al., 2019). Today, in some places, they are already the present (Toh et al., 2020).

Civil and environmental engineers play significant roles in shaping and designing urban and built environments. In a future where data is constantly collected, analyzed, and acted upon to improve quality of life and services in cities, civil and environmental engineers will need expanded competencies.

In recent years, our department has responded to this. We have conceived of and are implementing a sequence of three computational/data analysis courses. This spring, we are offering a sensing course for the first time. And we have worked to integrate sensing and sensing data analysis and interpretation into our project sequence (required semester-long courses of Civil and Environmental Engineering students their sophomore, junior, and senior years).

Our junior-level, semester-long Civil and Environmental Engineering (CEE) project course is nine "units" (at our institution one unit connotes, on average, one hour of student work per week of the course). All junior CEE students are required to take the course. Our CEE students are also required to take a sophomore and senior project courses. Non-CEE students typically do not enroll in these courses. Typically, the number of students in each course ranges between 25 and 40 students. The junior course consists of three projects, with each taking about one month and being completed in groups of three to five students.

In the past five years, the junior-level project course has typically included a project involving sensing and data analysis. This year, with 26 students enrolled in the course, for the first time, we deployed a smart cities project that gave students the opportunity to implement different stages of a real-life engineering project: design, sensing, deployment, data analysis, and decision-making amid uncertainty. For the project, each group of students created a pedestrian tracker using an Arduino and two passive infrared (PIR) sensors. Groups then deployed their data acquisition modules in two locations within our CEE department with the goal of offering guidance to the department about the use and/or traffic through its spaces. Computer vision-based and WiFi-enabled smart cities technologies can be the most informative, but since they capture users' personal information they may elicit public opposition. Conversely, PIR sensors are anonymous and privacy-preserving (Akhter et al., 2019). The choice of using PIR sensors for our project provides students two takeaways: !1) users' perception is an important consideration for engineers, and (2) the "best" solution is not always the most suitable solution. Moreover, when designing their data acquisition module, students also had to account for uncertainty. For example, PIR sensors would not only be triggered by the passing of humans, they would also be triggered by domestic animals. We aimed to convey the idea that all engineering problems inevitably have uncertainty that needs to be properly managed.

The project's overarching objective was to increase students' appreciation of the importance of coding, sensing, and data analysis for CEE. Skill-oriented objectives included increasing students' ability to code, analyze data, implement sensing and experiments while minimizing uncertainty, and make data-informed decisions.

In this report, we discuss lessons learned from our smart cities project. We assessed the project's efficacy by quantifying students' perception of growth over the course of the semester. We also collected qualitative data by asking students about their experience. Along with our results, we share ideas for improving the project.

Methods

Our Civil and Environmental Engineering junior project course consists of students majoring in Civil and Environmental Engineering. In Fall 2021, 26 students took the course.

The course intends to provide opportunities for students to engage engineering challenges in real-world contexts. We intend for students to advance their design, communication, and teamwork skills through hands-on experiences. We also aim for students to improve their understanding of the professional and ethical aspects of engineering projects. Every fall the course features three open-ended projects: a construction or build project; a sensing and data analysis project; and a sustainability-focused environmental project.

Students complete projects in groups. They are tasked with navigating uncertainty around the definition of the project in the planning phase. They complete the task, and the project culminates with a demonstration or a presentation where they communicate what they have done and why.

This was the first year we used our "smart cities" project. The project was possible because a faculty member with sensing expertise engaged with the teaching professor who was leading the project. A master's student who had worked with the sensing expert then worked with the teaching professor to identify specific supplies required, objectives that should be part of the project, and sensing and coding content that needed to be taught. The master's student was engaged throughout the project. He was critical to the success of the project.

After the students had completed the project, students were asked to complete a survey where they quantitatively and qualitatively assessed. For the quantitative assessment, students scored themselves on a Likert scale from 1 to 4 for several questions about the project objectives (**Table 1**). Qualitative assessment data came from the following question:

> Please list the biggest takeaways from Project 2. What skills and/or content did you learn from the project?

It is important to be clear that our data was limited to student perceptions of their change in understanding. It is also important to be clear that only data at the end of the project were captured. The teaching professor had consulted an assessment expert in our university's teaching excellence center to address limitations in a previous study. That prior consultation led us to use the Likert scale and qualitative assessment questions. In the Results & Discussion section, we discuss how our assessment and data collection strategies could have been improved.

To analyze our data, we calculated the average and standard deviation of the students' Likert scale responses for the overall group (25 of 26 students responded). To assess generalizability, i.e., statistical significance, for the overall group, we used a Wilcoxon signed-rank test, a non-parametric equivalent to a paired t-test (Wilcoxon, 1945). We performed statistical analyses in SPSS.

Table 1*. Questions posed to students to assess their perceptions of growth after completing the project.*

Topic	Question
Appreciation of coding, sensing, and data analysis	On a scale of 1 to 4, rate yourself according to your **pre**-Project 2 appreciation of the value of coding, sensing, and data analysis for CEE projects. On a scale of 1 to 4, rate yourself according to your **post**-Project 2 appreciation of the value of coding, sensing, and data analysis for CEE projects.
Ability to code	On a scale of 1 to 4, rate yourself according to your **pre**-Project 2 comfort with coding for CEE projects. On a scale of 1 to 4, rate yourself according to your **post**-Project 2 comfort with coding for CEE projects.
Ability to analyze data	On a scale of 1 to 4, rate yourself according to your **pre**-Project 2 ability to analyze data for CEE projects. On a scale of 1 to 4, rate yourself according to your **post**-Project 2 ability to analyze data for CEE projects.
Ability to integrate sensing	On a scale of 1 to 4, rate yourself according to your **pre**-Project 2 ability to integrate sensing into CEE projects. On a scale of 1 to 4, rate yourself according to your **post**-Project 2 ability to integrate sensing into CEE projects.
Ability to carry out experiments	On a scale of 1 to 4, rate yourself according to your **pre**-Project 2 ability to carry out experiments for CEE projects. On a scale of 1 to 4, rate yourself according to your **post**-Project 2 ability to carry out experiments for CEE projects.
Ability to make data-informed decisions	On a scale of 1 to 4, rate yourself according to your **pre**-Project 2 ability to make data-informed decisions for CEE projects. On a scale of 1 to 4, rate yourself according to your **post**-Project 2 ability to make data-informed decisions for CEE projects.
Understanding of smart cities	On a scale of 1 to 4, rate yourself according to your **pre**-Project 2 understanding of "smart cities." On a scale of 1 to 4, rate yourself according to your **post**-Project 2 understanding of "smart cities."

Results and Discussion

Quantitative

For each objective, we surveyed students (25 out of 26 students) to assess their perceptions of their pre- and post-project appreciation, ability, or understanding (subsequently referred to as “abilities”) of the seven project objectives (**Table 2**). We used a Wilcoxon signed-rank test to assess generalizability (or statistical significance) of any differences found between the means and standard deviations for pre- and post-project abilities (Wilcoxon, 1945). Through the test, we identified students' perceptions of their pre- and post-project abilities to be statistically significant for four of the seven course objectives (**Table 3**): appreciation of coding, sensing, and data analysis, ability to analyze data, ability to integrate sensing, ability to make data-informed decisions, and understanding of smart cities.

***Table 2**. Students' perceptions of their pre- and post-project appreciation, ability, or understanding for the assessed project objectives reported by the 25 students (out of 26) who completed the survey.*

Student	Appreciation of coding, sensing, and data analysis		Coding comfort		Abilty to analyze data		Ability to integrate sensing		Ability to carry out experiments		Ability to make data-informed decisions		Understanding of smart cities	
	Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*
1	3	3	2	3	3	4	2	3	3	4	3	4	2	3
2	2	2	2	2	1	1	2	2	2	2	3	2	2	2
3	1	3	3	3	3	3	2	3	3	3	3	3	2	3
4	2	3	2	3	2	4	1	3	2	3	3	3	1	2
5	1	3	1	1	3	4	2	3	1	2	3	4	2	2
6	3	3	1	1	2	3	2	3	3	3	2	3	1	3
7	3	4	1	2	3	4	2	2	2	3	3	4	2	2
8	3	3	1	3	3	3	2	3	3	3	4	4	2	3
9	2	4	3	4	4	4	4	4	2	3	3	3	3	3
10	2	3	1	1	2	2	2	2	3	3	3	3	2	2
11	2	3	1	1	3	3	1	2	3	2	3	3	3	3
12	1	1	1	1	2	2	2	2	3	3	3	3	2	2
13	4	4	3	3	3	3	3	3	3	3	3	3	2	3
14	3	4	3	3	3	3	3	4	3	3	3	3	3	3
15	2	4	3	3	2	3	2	3	2	2	2	3	2	2
16	4	4	2	2	3	3	2	3	3	3	2	3	2	2
17	4	4	3	3	3	3	3	3	4	4	3	3	3	3
18	2	3	1	2	3	4	2	3	2	4	2	4	2	3
19	3	3	4	3	3	3	4	3	2	2	3	3	2	3
20	3	3	1	2	3	3	1	2	3	3	3	3	3	4
21	2	4	2	2	3	3	1	3	3	3	3	3	2	4
22	3	3	4	3	4	4	3	3	2	2	4	4	2	2
23	2	2	2	2	4	4	1	1	4	4	4	4	1	1
24	3	2	3	2	4	2	4	2	3	2	3	3	4	4
25	2	3	2	2	2	2	1	1	3	3	2	2	2	2
Average	2.48	3.12	2.08	2.28	2.84	3.08	2.16	2.64	2.68	2.88	2.92	3.2	2.16	2.64
Standard Dev	0.85	0.77	0.98	0.83	0.73	0.80	0.92	0.74	0.68	0.65	0.56	0.57	0.67	0.74

Table 3. *Results of statistical analyses of students' perceptions of their pre- and post-project appreciation, ability, or understanding for the assessed project objectives reported by the 25 students (out of 26) who completed the survey.*

Course Objective	Timing	Mean	Std Dev	Min	Max	Z value	Probability
Appreciation of coding, sensing, and data analysis	Pre	2.48	0.85	1	4	-3.08	0.0021
	Post	3.12	0.77	1	4		
Coding comfort	Pre	2.08	0.98	1	4	-1.31	0.19
	Post	2.28	0.83	1	4		
Ability to analyze data	Pre	2.84	0.73	1	4	-2.02	0.044
	Post	3.08	0.80	1	4		
Ability to integrate sensing	Pre	2.16	0.92	1	4	-2.67	0.0075
	Post	2.64	0.74	1	4		
Ability to carry out experiments	Pre	2.68	0.68	1	4	-1.44	0.15
	Post	2.88	0.65	2	4		
Ability to make data-informed decisions	Pre	2.92	0.56	2	4	-2.13	0.033
	Post	3.20	0.57	2	4		
Understanding of smart cities	Pre	2.16	0.67	1	4	-3.15	0.0016
	Post	2.64	0.74	1	4		

Qualitative

All students qualitatively described their perceptions of their appreciation, ability, or understanding of for the seven course objectives assessed. Generally, students' qualitative descriptions aligned with our quantitative data. Specific responses varied, but generally highlighted consistent themes. Students expressed an improved appreciation for the value of sensors and their role in informing decisions. They also recognized the importance of sensing to smart cities technologies and that of coding to civil engineering, as well (**Table 4**).

Table 4. *Compelling qualitative descriptions of students' self-reported takeaways, skills, and/or content derived from our smart cities project.*

Student	Quote
A	"Making informed decisions through data collected from sensors enabled me to really experience and see the value of sensors in making decisions. Thinking about various sources of uncertainty was also valuable in that it allowed us to look for ways to minimize uncertainty to acquire better data."
B	"Using sensors to conduct experiments and making informed decisions/recommendations based on that. This concept is very important in smart cities, so it was great delving deeper into this!"
C	"As much as we would like coding to go away, the future of civil engineering definitely involves using coding. This is an important skill that we should definitely be taking more seriously."

Improving our assessment and data collection

Our study demonstrated that students' perceptions of multiple abilities relevant to the project increased. To come to this determination, we asked students to rate themselves at a single time point -- the end of the project -- according to their perceived understanding at the beginning and end of the project. Asking them only at the end of the project is not ideal; we would have preferred to have had asked them at both the beginning and end of the project.

Similarly, our qualitative data analysis could have been improved by probing students before and after the project. It could have also been improved by asking students about the specific aspects of the project that allowed for their growth.

We could also ask many other questions about the degree and longevity of the project's impact. For example, we could collect data on students' performance in the computational applications course that they will take after our course. We could also attempt to assess any changes in their undergraduate trajectories from having been exposed to this content, e.g., do they enroll in courses related to the smart cities project in their final three semesters? We would, of course, like to think that this project (and our course generally) had a real impact on our students, but more robust data, perhaps in the form of longer-term, longitudinal studies, would be needed.

Conclusion

We developed a pedestrian tracking smart cities project in our junior-level Civil and Environmental Engineering course. The project aimed to improve students' understanding of smart cities. It also intended to give students the opportunity to apply the experimentation, coding, data analysis and interpretation that are all required in many smart cities initiatives. Our data show that, through the project, students felt that they: gained both greater understanding of smart cities and appreciation for the relevance of coding, sensing, and data analysis to Civil and Environmental Engineering contexts; and they improved their abilities to analyze data, integrate sensing, and make data-informed decisions.

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