Teaching Statistics Using Facility Location Modeling: A Course-based Undergraduate Research Experience

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Abstract: There is a growing need to expand and strengthen the industrial engineering/operations research workforce. Undergraduate research experiences are an effective way to build in-demand skills and to attract people to science, technology, engineering, and mathematics fields, such as industrial engineering/operations research. However, the traditional apprenticeship model of an undergraduate research experience limits the number of undergraduate students who can access research opportunities. Course-based undergraduate research experiences (CUREs) are learning experiences in which whole classes of students conduct research to address questions or problems without known outcomes. To broaden access to research opportunities within operations research, we designed and piloted a CURE in an introductory statistics course taught by industrial engineering/operations research faculty, taken by non-major students. In our CURE, groups of students formulated and answered research questions related to geographic access to social services in their metro area. This was done through a guided process that included lectures on data collection, facility location modeling, and communication with non-technical stakeholders. We used survey data to assess the CURE's impact on students' attitudes and self-reported research skills. We found that this CURE effectively builds in-demand research skills.

1 Introduction

The demand for skilled industrial engineers and operations research analysts is expected to grow, as technological advances have made it faster and easier to collect data that can be used to improve business decision-making, enhance government efficiency, and reduce costs while maintaining quality. According to the National Science Foundation, employment in science, technology, engineering, and mathematics (STEM) occupations is expected to grow faster than in non-STEM occupations (7% vs. 2%) (National Center for Science and Engineering Statistics, 2024). Within the broader STEM fields, the Bureau of Labor Statistics projects that there will be a 23% increase in employment of operations research analysts and a 12% increase in employment of industrial engineers from 2023 to 2033 (Bureau of Labor Statistics, 2024). A 2024 survey from the National Association of Colleges and Employers (NACE) highlights how employers are looking for skills beyond technical capabilities. While 73% of employers stated that they seek technical skills on a candidate's resume, 88% stated they seek problem-solving skills, 81% stated they seek the ability to work in a team, and 77% stated that they seek written communication skills (NACE, 2024). Moreover, this survey highlights that critical thinking and communication were among the career competencies that have the largest gaps between the employers' stated importance and the employers' rating of recent college graduates' proficiency. Altogether, these trends motivate the need to strengthen the STEM workforce and develop both technical and non-technical skills among future professionals working as or collaborating with industrial engineers and operations researchers.

As a recognized high-impact practice with significant educational benefits, undergraduate research experiences (UREs) provide students with valuable opportunities to develop these skills. In addition to technical skills, undergraduate students who engage in high-quality research experiences also develop non-technical skills that map onto the eight career competencies identified by NACE as important for the workforce (Mekolichick, 2023). For example, students at Florida Gulf Coast University who participated in an undergraduate research capstone demonstrated greater skills in critical thinking and written communication than peers who participated in an alternative capstone experience (Gunnels et al., 2024). Likewise, Blessinger and Hensel (2020) found that undergraduate research improves teamwork skills.

Traditionally, UREs have followed an apprenticeship model, where students work within faculty-led research groups, and receive mentoring from faculty or graduate students. While this model can provide rich and personalized learning, it also limits access to research opportunities. Students who participate in traditional UREs tend to be those with strong academic records or the confidence to approach faculty directly. This can lead to selection bias in the types of students who have access to these experiences. The National Academies of Sciences, Engineering, and Medicine have emphasized the importance of rethinking this approach (National Academies of Sciences and Medicine, 2017), encouraging institutions to develop more inclusive and scalable models that make meaningful research experiences accessible to a broader and more diverse group of students.

To address the limited access to UREs, educators are exploring ways to involve more students in research. Course-based undergraduate research experiences (CUREs) have gained significant traction as one such approach. A CURE is "a learning experience in which whole classes of students address a research question or problem with unknown outcomes or solutions that are of interest to external stakeholders" (Dolan, 2016). CUREs are integrated directly into courses, giving all students in the class the opportunity to participate in projects that feature elements of discovery and relevance that transform a typical class project into a true research project (Auchincloss et al., 2014). Important elements of CUREs include improved scientific practices, collaboration, discovery, iteration, and relevance (Auchincloss et al., 2014). The benefits of CUREs are not restricted to content knowledge: CUREs have been associated with cognitive gains, psychosocial gains (e.g., self-efficacy and project ownership), behavioral gains (e.g., persistence in a STEM major), and affective gains (e.g., increased enjoyment and motivation in STEM courses) (Dolan, 2016).

While CUREs lower the barriers that prevent students from engaging in research, their implementation remains uneven across disciplines. CUREs originated in the life sciences and to date most published CUREs are concentrated in biological and chemical sciences (Buchanan and Fisher, 2022). Engineering, mathematics, physics, and geoscience remain underrepresented, with only 8% of published studies falling within these areas (Buchanan and Fisher, 2022). To address this gap, Buchanan and Fisher (2022) suggest designing new CUREs in disciplines that have not yet explored these types of experiences in their classrooms.

This paper responds directly to that call by presenting a CURE in the field of industrial engineering/operations research (IE/OR). Specifically, we describe our effort to incorporate a CURE involving facility location modeling into an introductory statistics course offered to non-OR students by the IE/OR department at Georgia Tech (GT). We hypothesize that the CURE is effective at building critical research skills, which are valuable in both the workforce and graduate studies, enhancing student engagement and interest in statistics and IE/OR. Our secondary hypothesis is that exposing students to IE/OR through a CURE may increase student interest in a career in an IE/OR related field.

The remainder of this article is organized as follows: Section 2 provides background on the CURE initiative; Section 3 outlines the course goals and learning objectives; Section 4 details the design of the CURE; Section 5 explains how the CURE was evaluated; and Section 6 presents reflections from the instructor and study team. Finally, Section 7 offers concluding remarks.

2 Background

2.1 Background on ISYE 3770: "Statistics & Applications"

We integrated our CURE into ISYE 3770. At GT, ISYE 3770 - "Statistics & Applications" is a course that is delivered by IE/OR faculty to non-IE/OR majors. The course is a graduation requirement for many students majoring in computer science as well as mechanical, electrical, and civil engineering. The course is an introduction to probability, focusing heavily on applications. Like other introductory probability and statistics courses, it includes common probability distributions, point estimation, construction of confidence intervals, linear regression, and analysis of variance. All students who take the course are required to have taken a multi-variable calculus course, but do not need to have prior experience with statistics or probability. For many students, ISYE 3770 is the only course that they take that is taught by the IE/OR department.

2.1.1 Student Population

ISYE 3770 attracts a student population with different fields of study. From 2023-2025, most students enrolled were majoring in computer science, with significant minorities of students coming from mechanical, electrical, and civil engineering. Environmental, chemical, and biomedical engineering, as well as neuroscience, represented small minorities in the student population.

Most students taking ISYE 3770 had been enrolled at GT for three to five semesters, not including summer terms, and nearly all were taking the course for the first time. Previous experience with mathematics varied. On a pre-course survey, some students noted past difficulties and concerns about their readiness, while others reported feeling confident, having completed courses such as calculus, linear algebra, and discrete mathematics. Only a small number had taken AP Statistics in high school, suggesting that for most, this course would be their first formal exposure to statistical thinking.

Students were asked to rate their mathematical background on a scale from one to five. Most selected either a three or a four, indicating that they felt reasonably prepared. Interest in the course also varied. A majority (52%) described their interest level as "so so," a large minority (36%) said they were excited to learn, and a small minority (12%) indicated that they were taking the course primarily to fulfill a requirement. These responses show that while some students enter the course with enthusiasm, most approach it with a neutral or goal-oriented mindset.

2.1.2 Student Motivations

When asked about their goals for the course, students provided a wide range of responses. Approximately a third of students hoped to build a strong conceptual understanding of statistics. A minority emphasized the importance of applying statistical tools to real-world problems (8%), connecting the course directly to their future careers (9%), and a desire to improve their confidence in math (8%). 10% of students were explicitly focused on earning a high grade.

3 CURE overview, goals, and learning objectives

3.1 CURE Overview

In this CURE, groups of students formulated and answered research questions related to access to services within Atlanta, Georgia. Students were provided with lectures and resources on data collection procedures, facility location modeling, and data visualization. First, groups collected data on the current locations of services (e.g., food-pantries) and candidate locations that could be options for expanding these services (e.g., places of worship). They also collected data on where demographic groups of interest for whom they wanted to improve access (e.g., women of reproductive age) lived. Then, the students were shown how to use different optimization models to analyze the best locations for expansion. Finally, the instruction team presented a lecture on how to identify and communicate with problem stakeholders. At the end of the CURE, students presented their findings to peers in a mock conference and wrote an executive summary to share their findings with relevant stakeholders.

3.2 Goals of the CURE

Before developing detailed materials for the CURE, we defined that our goals for the CURE were to:

1. Build interest in statistics through exposure to real-world applications of industrial engineering.
2. Build transferable research skills.
3. Increase awareness of what industrial engineers do and industrial engineering's relation to other fields.
4. Expose students to open-ended questions in engineering.
5. Motivate students to consider industrial engineering/analytics as a field of study and career path.
6. Motivate students to consider research and graduate school as a post-graduation plan.

3.3 Learning Objectives

We also specified learning objectives for students participating in the CURE. We stated that after the CURE, students should be able to:

1. Describe the key components of an optimization model.
2. Collect appropriate data sources as input into classic optimization models.
3. Apply a mathematical model to evaluate current access to services.
4. Use statistics to assess strengths and weaknesses of different optimization models to improve access.
5. Interpret the model solutions and assess their impact on different populations using statistical methods.
6. Identify relevant stakeholders impacted by proposed solutions.
7. Produce and justify solution recommendations for stakeholders.

4 CURE Structure

Over the course of the 15-week semester, we delivered instruction for the CURE in four modules (see Table 1). The first three modules had a corresponding lecture, while the last module involved student presentations. Each module had a corresponding assignment.

The first module (§4.2) focused on the data inputs for optimization models and was delivered during week 6. The second module introduced facility location problems (§4.3) and was delivered during week 8. The third module (§4.4) focused on stakeholder engagement and communication and was delivered during week 11. The last module (§4.5) consisted of summative presentations and reports that were submitted during the final week of the course. The lectures and assignments scaffolded student learning by systematically expanding students' skills and project components. All assignments and grading rubrics are included in Appendix D.

Module	**Corresponding Learning Objective(s)**	**Formative Assessment**		**Summative Assessment**
	Students will be able to:	*During lecture/class time:*	*After the lesson, students will:*	*For the final assessment, students will:*
1	**#1** Describe the key components of an optimization model. **#2** Collect appropriate data sources as input into classic optimization models.	**Lecture 1:** (Section 4.2.1) - Instructors present an example optimization model expanding food pantries - Instructors lead a tutorial demonstrating how to scrape facility locations from Open Street Maps	- Define a service of interest (SOI) and candidate facilities. - Modify provided code to locate SOI facilities - Modify provided code to gather demographic data.	**Assignment 1:** (Section 4.2.2) - Produce data inputs for SOI necessary for an optimization model. - Generate a map showing the existing locations of SOI in Atlanta, Georgia
2	**#3** Apply a mathematical model to evaluate current access to services. **#4** Use statistics to assess strengths and weaknesses of different optimization models to improve access.	**Lecture 2:** (Section 4.3.1) - Instructor presents a simple facility location optimization model to build intuition - Instructor presents 5 classic optimization models of access.	- Select two optimization models based on SOI - Choose appropriate parameters for selected models - Compose data with selected models and parameters	**Assignment 2:** (Section 4.3.2) - Generate a histogram of travel times to SOI based on solutions to two different optimization models - Compare these solutions and corresponding access to the current state
3	**#5** Interpret the model solutions and assess their impact on different populations using statistical methods. **#6** Identify relevant stakeholders impacted by proposed solutions. statistical methods	**Lecture 3:** (Section 4.4.1) - Instructors discuss a stakeholder is and elicit examples from the class - Instructors demonstrate how to generate statistical communications that are interpretable to a diverse set of stakeholders	- List key problem stakeholders - Construct plots to communicate results to stakeholders	**Assignment 3:** (Section 4.4.2) - Adapt provided code to answer questions of which facilities open under what expansion policies and which populations are impacted under each expansion policy
4	**#7** Produce and justify solution recommendations for stakeholders.	**Students' Presentations:** (Section 4.5) - Students present SOI expansion work to 10-15 peers, representing "mock stakeholders" - Students receive questions and peer feedback from the audience of mock stakeholders - Evaluate peer presentations	- Complete executive summary of presented work	**Assignment 4:** (Section 4.5.1) - Assemble models, figures, and findings into a summary writeup - Argue selected models correctly described problem and that the identified policy is optimal. - Critique modeling simplifications where appropriate.

Table 1: The modules, lectures, and assignments delivered during the CURE and their connections with the learning objectives
SOI: service of interest

4.1 Project On-boarding and Introduction

During the first week of the course, students were given a 10-minute introduction to both the CURE and the instructors who would join the instructional team for the CURE modules. We communicated our main goals to students; to give them exposure to a real-world application of industrial engineering; to build transferable research skills; to teach them about what IE/OR does and its position relative to other fields; to demonstrate an open-ended research question in engineering. After introducing students to the CURE, we asked them to fill out a pre-CURE survey instrument (described later in Table 2). Additionally, we assigned students to teams of three or four to complete the CURE. There were 59 students who completed the course, whom we grouped into 19 groups.

4.2 Module 1: Collecting Data for Optimization Models

During week 6 of the course, we presented the first CURE module which had an interactive lecture and a final summative assignment that was to be turned in during week 8. With this module, our key learning objective was that students would be able to collect and understand data as inputs to classic facility location problems.

4.2.1 Lecture 1: Spatial Data as Model Inputs

We first taught students how to construct a research question and then illustrated appropriate spatial data inputs for a facility location optimization model that could answer such a question. To pique student interest, we also emphasized the transferable technical skills, notably spatial data, familiarity with demographic data, and use of contemporary optimization solvers. We began by introducing a generic shared research question:

> *Which locations (among a set of **candidate locations**) should we select to expand a **service of interest** for a **geographic region**? How do these decisions impact different **populations of interest**?*

We then concept mapped the bolded key words onto a completed example, hereafter referred to as the food pantry example. Our example research question was:

> *Which **places of worship** should we select to include **food pantries** in **Atlanta, Georgia**? How do these decisions impact **women of childbearing age**?*

We presented results from an optimization model designed to solve this question, providing an early example of the kind of analysis, stakeholder identification, and policy recommendation that would result from the CURE.

Leaning on the food pantry example, we discussed what spatial data were required for the optimization models. Few students had prior experience with spatial data, so we taught basics about vector spatial data. Then we moved on to demonstrating how students could gather their own vector data. We showed students three different methods for finding data: via a mapping application programming interface (API), manual encoding, or pre-compiled data. In an accompanying Jupyter notebook, students were given examples of each data gathering method. The handout asked students to make minor code changes. When these changes were made, the handout would gather the data used in the food pantry example.

4.2.2 Assignment 1

In the first assignment, each team developed their research question. For example, one team's question was "Which parking lots could be expanded to community gardens to expand access for the elderly" After formulating their question, students had to collect spatial data on existing and potential facility locations and gather relevant demographic data using open sources, APIs, and web scrapers. Each group then processed and visualized their data within Atlanta, Georgia. We provided an auto-grader, against which students could test their submissions, and ample office hours to ensure proper formatting and projection. As these data would be used as inputs to optimization models, students spent considerable time cleaning their data. Each group turned in two spatial data sets and a map illustrating the spatial population distribution and service facilities.

4.3 Module 2: Facility Location Problems

In the second module, we introduced students to the concept of optimization modeling. This module consisted of one lecture and one assignment, and was delivered in the 11^{th} week of the course.

4.3.1 Lecture 2: Distances and Optimization Models

Lecture 2 taught students how to transform collected and processed spatial data into solvable optimization models. We began with a review of the research question that students had defined in Assignment 1. At this point we also introduced the simplifying assumptions for the Facility Location Problems (FLPs) which they would solve: notably using straight line distance and assuming that all populations of interest would seek care at their closest facility.

We then presented a simple three source, three sink example to help students intuit how to solve optimization problems under varying objectives. During the lecture in their project groups, students first discussed the relative merits of potential sink choices. We then introduced the fundamental optimization terms of infeasible, sub-optimal, and optimal solutions. By having students solve small examples by hand, we aimed to enable them to extrapolate how an optimization solver might work.

We did not require students to code the formulations of their own optimization models. Instead we gave students code corresponding to five classic facility location models. Students had to provide structured inputs based on their data and received consistent outputs. We presented five classic facility location model: a p-mean model, in which a decision-maker (DM) minimizes total distance subject while opening fewer than p facilities; a min-max model wherein the DM minimizes furthest travel distance under the same facility constraint; a set covering model in which the DM minimizes the number of facilities such that all population centers are ℓ-close to a facility; a percentile set covering model wherein the DM ensures that $q\%$ of the population is ℓ-close; and lastly a maximal-covering model wherein the DM is constrained by budget and maximizes the fraction of demand that is ℓ-close. Algebraic formulations and further details are available in Appendix C. In the accompanying Jupyter notebook handout, students were given instructions about the appropriate model-specific inputs for each listed model and example function calls. The final five minutes of class were set aside for students to meet in their groups and discuss what models would be most appropriate for their data.

4.3.2 Assignment 2

The second assignment built on the data collected in the prior module. First, we asked each group to consider their SOI and select an appropriate model from the five presented. Then using their previously compiled data, each group solved two different optimization models and gathered results. Each group turned in a modified version of their original data sets, with new columns representing the travel distances under each optimization model or the status of each facility.

4.4 Module 3: Stakeholder Engagement and Communication

The third module focused on non-technical communication. Specifically, the instructional team emphasized that modelers are obliged to consider stakeholders of the modeled system, such as decision makers and the people who will be impacted by such decisions, when building optimization models.

4.4.1 Lecture 3: Communicating to Stakeholders

Lecture 3 was delivered during the 11^{th} week of the course. We returned to the food pantry example and highlighted how much progress students had made on their specific research question. We then defined a stakeholder as *any individual impacted by the outcome of a project*, using the food pantry example to define a sample set of stakeholders. In groups, we asked students to build a list of stakeholders for their projects. After students had done this, we emphasized the importance, as modelers, of reporting optimization model results in a way that is easily interpretable by stakeholders. This segued into basic principles in statistical communication covering histograms, box plots, bar plots, and bubble plots. We also discussed best practices in communicating data using maps. The lecture concluded with students connecting their previously generated datasets into a mapping Jupyter notebook to confirm that each group could produce the visualizations discussed. The last 15 minutes of the course period were set aside for brainstorming appropriate visualizations for their identified stakeholders and planning for the rest of the project.

4.4.2 Assignment 3

Prior to the fourth module, each project group prepared a short presentation of the research they had conducted. We asked that students frame their research question, detail their data sources, and defend their model choice. Each group had to submit slides prior to the final module of the CURE.

4.5 Module 4: Presentations and Executive Summary

During the 15^{th} week of the course, we concluded the CURE with a mock conference session. We partitioned the 19 teams into 5 clusters. Each cluster shared a common topic in their research question, such as healthcare, the elderly, education, or green spaces. Each group had 12 minutes to present their work to their peers followed by 3 minutes for questions. Students provided feedback to their peers via peer-evaluation sheets. These peer evaluations were collected and used to assign grades to each group. Several days after the presentation, students also turned in written reports.

4.5.1 Assignment 4: Executive Summary

We asked students to prepare an executive-summary-style policy brief which could be delivered to a stakeholder. The report mirrored the structure of the presentation, including a problem statement, description of data sources, detailed explanations of the optimization models, and a comparative analysis of their models. Each group was asked to deliver a single policy recommendation and reflect on the limitations of their models.

5 Evaluation of course goals and student learning

In this section, we present the results from pre- and post-course surveys that evaluated the CURE, as well as other feedback the instructor team received. To evaluate the potential benefits of the CURE, we conducted surveys of students in multiple sections of ISYE 3770 course: three traditional (control) sections and one CURE section. Each of these sections was delivered in Spring 2025. The control sections were all taught by a single instructor and the CURE section was taught by a different instructor. Both instructors covered similar content, used similar syllabi, had previously taught the course, and awarded similar grade distributions at the end of the course. We then compared the pre- and post-surveys among these different sections.

5.1 Evaluation Instruments

We evaluated the CURE using pre- and post-surveys adapted from Lopatto (2018) that asked students about their post-graduation plans, levels of experience with various course elements, attitudes towards engineering, and perceptions of industrial engineering. An overview of the pre-survey and post-survey structure is shown in Table 2. The first blocks ensured that participants were at least 18 years old and consent to participate in the study. Those who did not meet these criteria were immediately directed to the end of the survey. Those who were eligible and had consented to participate were asked to provide the last four digits of their phone number, which was then used by the study team to match pre-course responses to post-course responses.

Blocks 3, 4, 5, 6, and 7 asked about career goals and ambitions, prior experience with course elements, attitudes towards engineering, attitudes towards and interest in industrial engineering and related analytics fields. Block 3 asked students about their current academic studies and their post-graduation plans. These questions were created to assess to the extent to which students' attitudes, career ambitions, and interests changed as a result of taking ISYE 3770 and whether there were differences between the CURE and control sections of the course. Block 4 asked students about their experience with both technical and non-technical research skills, which were created to observe the extent to which students' self-reported proficiency with such skills changed as a result of taking the CURE. Block 5 asked students about their attitudes towards problem solving in engineering and their ability to succeed in engineering. Block 6 asked about students' ability to relate industrial engineering (IE) concepts into the real-world, awareness of IE, and interest in IE. Block 7 had much the same aims as Block 6, but asked students to provide free responses rather than using a Likert scale. Block 8 asked for additional demographic information to evaluate whether changes varied across demographic groups. The complete pre- and post-course survey instruments are provided in Appendix E.

In addition, we reviewed responses to the course evaluation conducted at the end of the course. These surveys offer opportunities for students to comment on the greatest strengths and weaknesses of the course and the instructor. We also received several unsolicited comments from students during and after the course. We summarized these unsolicited comments as part of our evaluation.

5.2 Results of the Student Survey

Table 3 summarizes the respondents to our pre- and post-course survey in both the CURE and control sections. Among the 63 students who were enrolled at the beginning of the semester in the CURE section, 37 students (58.8 %) responded to the pre-course survey, while 81 students (28.5%) of the 224 students enrolled in the control sections responded to the pre-course survey. Among the 59 students who did not withdraw from the CURE section at the end of the semester,

Table 2: An overview of the pre-course and post-course survey delivered to students in both CURE and control sections of ISYE 3770.

Block	Description & Examples of Questions in Block	Response Type
0	*Confirming 18 years or Older* Are you at least 18 years old?	Yes/No
1	*Consent* Do you agree to be in the study?	Yes/No
2	*Respondent Information* Please type the last four digits of your phone number. This information will be used confidentially to match pre-course data to post-course data by the researchers and will not be shared with the instructor of ISYE 3770.	Four digits
3	*Career Goals and Ambitions* Have you declared a major yes? Which major have you declared? Please indicate how likely you are to do each of the following in the first year after graduation • Pursue a job in engineering/data science/analytics • Pursue a job outside of engineering/data science/analytics • Pursue graduate school in engineering/data science/analytics • Pursue graduate school in a something other than engineering/data science/analytics	Yes/No Short text response 5-point scale
4	*Prior Experience with Course Elements* What is your level of experience with the following working styles? • Working individually • Working in small groups • Becoming responsible for part of a project What is your level of experience with the following research skills? • Collecting and cleaning data • Data analysis • Computer modeling • Working with large datasets • Automating data collection • Visualizing data using graphs and charts • Visualizing data using maps What is your level of experience with the following presentation skills? • Presenting results orally • Presenting results in written papers or reports • Critiqueing the work of other students	5-point scale 5-point scale 5-point scale
5	*Attitudes Towards Engineering* Please rate your agreement with the following items: • Even if I forget the facts, I'll still be able to use the thinking skills I learned in engineering. • I can rely on scientific results to be true and correct. • The process of writing in engineering is helpful for understanding engineering ideas. • Engineering instructors should just tell us what we need to know so we can learn it. • Creativity does not play a role in engineering. • Engineering is connected to non-engineering fields such as history, literature, economics, or art. • When experts disagree on an engineering question, it is because they don't know all the facts yet. • Engineering is essentially an accumulation of facts, rules, and formulas. • Since nothing in science is known for certain, all theories are equally valid. • I can do well in engineering courses. • Solving engineering problems requires following a scientific method in a straight line. • Too much emphasis in engineering classes is placed on figuring things out for yourself • Engineers know the right approach to a problem before they start to solve it	5-point Likert Scale
6	*Attitudes Towards and Interests In Industrial Engineering and Related Skills* Please rate your agreement with the following items: • I can identify appropriate statistical analyses to answer questions about real-world problems. • I can recognize when mathematical modeling is appropriate to solve a problem. • I can communicate findings of a statistical analysis to an audience of non-specialists. • I know what industrial engineers do. • Industrial engineering concepts are relevant to my life. • Industrial engineering can improve people's lives. • I am interested in pursuing further coursework in industrial engineering. • I am interested in pursuing research in industrial engineering. • I am interested in majoring in industrial engineering.	5-point Likert Scale
7	*Knowledge of Industrial Engineering* How would you describe the field of industrial engineering? What interests you about industrial engineering? What are the most important skills for industrial engineers to possess? If you plan to major in something other than industrial engineering, in what ways do you expect industrial engineering to relate to your intended field of study? In your own words, how has your understanding of industrial engineering changed this semester?*	Free-text Free-text Free-text Free-text Free-text
8	*More Respondent Information* What is your gender? How would you describe yourself? (Race/ethnicity) Prior to this semester, how many semesters of college study did you have? Please exclude semesters you've spent on co-op. What is your domestic/international student status? What is your parents' highest level of education?	Multiple choice Checkboxes Multiple choice Multiple choice Multiple choice

* This question was only asked on the post-course survey.

	CURE		Control	
	Pre	Post	Pre	Post
Students (#)	63	59	224	209
Responses	37 (58.8%)	34 (57.6%)	81 (28.5 %)	39 (18.7%)
Shared Respondents	22 (10.5%)		21 (36.5%)	

Table 3: Number of participants in control and CURE sections, number of respondents to each survey and number of individuals who had matched (pre- and post-) responses.

34 (57.6%) completed the post-course survey. 21 students (36.5%) in the CURE section completed both surveys. Of the 224 students enrolled in control sections of the course, 15 withdrew. 81 (28.5%) completed the pre-course survey and 39 (13.7%) completed the post-course survey. In the control sections, 22 (10.5%) completed both surveys. A summary of demographic information for all respondents is provided in Appendix Table 5.

5.2.1 Demographics of Respondents

Throughout the remainder of this section (§5.2), we report results considering only those who completed both the pre- and post-course survey and were able to be matched through their four-digit phone number identifier. Table 4 shows the demographics of those who responded to both the pre- and post-course surveys within the CURE and control sections. 24% of the post-course CURE respondents were female compared to 45% of the post-course control respondents. 76% of the post-course respondents in the CURE section were domestic students, compared to 64% in the control sections. Overall, we observed that respondents in the CURE section reported higher rates of having parents with higher levels of education. However, the non-response rate was higher in the control section. Further, respondents from the CURE section were more likely to identify as Asian/Pacific Islander. The vast majority of students (90%) of students in the CURE section had only 1-2 remaining semesters, whereas only 18% of students in the control sections had 1-2 remaining semesters.

5.2.2 Research Skills

Figure 1 illustrates the self-reported experience with certain research skills at the beginning of the semester and the end of the semester for both the CURE section and control sections. Within the CURE section, students reported gaining experience in working with large datasets, visualizing data using maps, and visualizing data using plots and graphs. For example, 25% of students in the CURE section reported having either a little to no experience with data analysis prior to participating in the CURE. After participating in the CURE only 5% of students still reported little to no experience with data analysis. In the control section, 16% of students reported having little to no experience with data analysis before the course and 26% reported having little to no experience following the course. Larger gains in experience within the CURE section were reported for all research skills about which we asked. These findings may indicate that the CURE was more effective at building these foundational research skills than a traditional offering of this course.

5.2.3 Attitudes about Engineering

Figure 2 illustrates the responses to questions on attitudes on engineering, with additional responses provided in Figure 3. We observed small shifts in how students perceived the problem-solving

Number of Shared Responses	Control		CURE	
	22	(10.6%)	21	(36.5%)
Reported Gender, n (%)				
Female	10	(45%)	5	(24%)
Male	8	(36%)	14	(67%)
Prefer not to say	0	(0%)	1	(5%)
No response	4	(18%)	1	(5%)
Reported Race, n (%)				
Asian/Pacific Islander	8	(36%)	11	(52%)
Asian/Pacific Islander,White/ Caucasian	1	(5%)	1	(5%)
Black	1	(5%)	0	(0%)
Hispanic / Latino	1	(5%)	1	(5%)
White/ Caucasian	6	(27%)	4	(19%)
Hispanic / Latino,White/ Caucasian	0	(0%)	2	(10%)
Prefer not to say	0	(0%)	1	(5%)
No response	5	(23%)	1	(5%)
International Status, n (%)				
Domestic student	14	(64%)	16	(76%)
International student	3	(14%)	4	(19%)
No response	5	(23%)	1	(5%)
Parental Education, n (%)				
Some grade/high school	2	(9%)	1	(5%)
Completed high school or GED	0	(0%)	1	(5%)
Some college/technical school	2	(9%)	1	(5%)
Bachelor's degree	6	(27%)	5	(24%)
Some graduate/professional school	0	(0%)	4	(19%)
Completed graduate/professional school degree(s)	7	(32%)	8	(38%)
No response	5	(23%)	1	(5%)
Prior Semesters at GT, n (%)				
1-2 semesters	1	(5%)	1	(5%)
3-4 semesters	11	(50%)	2	(10%)
5-6 semesters	5	(23%)	12	(57%)
More than 6 semesters	0	(0%)	5	(24%)
No response	5	(23%)	1	(5%)
Remaining Semesters at GT, n (%)				
1-2 semesters	4	(18%)	19	(90%)
3-4 semesters	11	(50%)	1	(5%)
5-6 semesters	1	(5%)	0	(0%)
More than 6 semesters	1	(5%)	0	(0%)
No response	5	(23%)	1	(5%)

Table 4: Demographic information of survey respondents

process, with both the CURE and control sections seeing small increases in disagreement with the statement that *engineers know the right approach to a problem before they start to solve it.* At the beginning of the course, just 10% of students in the CURE section disagreed with the statement *engineering is essentially an accumulation of facts, rules, and formulas.* In the post-course survey, 47% of the same students disagreed with the statement. The control group had both more initial disagreement (35%) and less final disagreement (38%).

After the semester had concluded, students who partook in the CURE were less likely to agree that solving engineering problems proceeds in a straight line than their peers in the control section. While the 14% change in the CURE section across the semester was minimally different from the 9% change in the control section, a much greater fraction (6% in control vs 22% in CURE) of students were likely to express strong disagreement. No other major differences, either from pre-to-post or between CURE and control were noted. These findings may indicate that participating in the CURE helped students recognize that there are different approaches to solving problems and how decisions in the research process may influence the findings.

In addition, we observed that 11% fewer students in the CURE section responded that they agreed with the statement "I can do well in engineering courses" after the CURE section relative to the responses at the beginning of the course (90% pre-course; 79% post-course). Meanwhile, the level of agreement with this statement in the control sections was unchanged before and after the course (89% pre-course; 89% post-course)

5.2.4 Career Goals and Ambitions

We next report on students' self-reported post-graduate plans. We observed an 11% reduction in the fraction of students reporting that they were likely to pursue graduate studies in engineering in the CURE section, although students who were extremely likely to pursue graduate education remained so. Conversely, in the control section, we note a 19% increase in students interested in engineering graduate education. We also observed a 16% reduction in CURE students who reported they were interested in a career in engineering, data science, or analytics, with no change noted in the control section. There was a small increase (13%) in CURE students interested in non-engineering graduate studies, but observed a similar (11%) increase in CURE students disinterested in non-engineering graduate studies. Likert plots of these findings are available in Figure 4. These findings indicate that the CURE may not be effective at encouraging students to pursue graduate studies in engineering. However, we caveat this finding by remarking that CURE students were closer to graduation than students in the control sections. Particularly on the questions about graduate education, we observed that the number of students who were neither likely nor unlikely to pursue graduate education increased in the control section while decreasing in the CURE section.

5.2.5 Attitudes Towards Engineering and Interest in Industrial Engineering

We observed small changes in student interest in further statistics or Industrial and Systems Engineering (ISyE) coursework. We find that in the CURE section, there were 28% and 16% increases in students dis-interested in further coursework in statistics and industrial engineering respectively. This trend was reversed in the control sections, with 18% and 27% decreases in students dis-interested in further statistics and industrial engineering coursework respectively. Both the control and CURE section observed similar negative shifts around interest in statistics research and neither section observed large shifts in student interest in industrial engineering research or in majoring in industrial engineering. A Likert plot of these results is available in Figure 5.

5.2.6 Knowledge of Industrial Engineering

From our free responses, we saw improvement in the understanding of what industrial engineering involves within the CURE section. We considered the responses to the question: "How would you describe the field of industrial engineering?" We observed that the number of students who answered that they were "Not sure" what industrial engineering was decreased in the CURE section, but increased or remained the same in the control sections. Moreover, we observed that the descriptions of what industrial engineering is improved for the CURE section. For example, one student before the CURE described industrial engineering as "Plant efficiency related." After the CURE, this same student described industrial engineering as "Making informed decisions for processes based on statistics and probabilities." Another student at the beginning of the course described industrial engineering as "Vast." After the CURE, this same student described industrial engineering as a "Vast field that incorporates concepts like statistics, stochastic, data analysis, logistics, and strategy to a variety of industries to help optimize processes."

5.3 Course Instruction Opinion Survey (CIOS) comments

In addition to the results of the pre- and post-course surveys, we also reviewed the responses to institutional course evaluations for the course. 49 students completed the Course Instruction Opinion Survey (CIOS). Unprompted, four students provided positive feedback about the CURE. These comments stated that the CURE was "helpful," "interesting," "a fun way to introduce us to real-world applications of statistics," and "did not interfere with what we were learning." One student provided negative feedback about the CURE, stating that it was "a waste of time and does not help us learn. ... I don't think it was a good idea to have it."

5.4 Unsolicited Feedback from Students

We also received several comments from students about the CURE. Most of this unsolicited feedback was positive, and some of it was constructive feedback to improve the CURE for future offerings. Students remarked in emails to the instructional team that the CURE allowed for creativity and provided a well-supported introduction to IE. However, some students perceived that the CURE was too ambitious for the course. One student remarked that students generally perceive that the effort expended on assignments should be proportional to the weight on their final grade. This student stated that, because the CURE was only worth 6% of the total grade for ISYE 3770, some students did not invest energy into the CURE as the perceived return on their investment might be minimal. Additional constructive feedback suggested that delivering the CURE as an immersive short course, either as a two-week consecutive module or as a standalone course, might better allow students to see the continuity of the research process. Further, two students reached out unprompted to the course instructors to express interest in pivoting their studies to pursue IE graduate school.

6 Reflections & Lessons Learned

After delivering this pilot of the CURE, we reflected on our experiences and the feedback received from students. The following are some of our observations that may influence how future iterations of the CURE are delivered.

6.1 Reflections on this CURE

We found that Lecture 1 was the most challenging to deliver. In hindsight, this lecture introduced a lot of new content to students, including the simultaneous introduction of research question development and spatial data concepts. In addition, we ran into some challenges with the coding notebook delivered during Lecture 1. The corresponding coding handout for this lecture, which was designed to help students explore these concepts on their own, assumed too much prior coding knowledge and experience in Python. This resulted in students having challenges in running our coding handout and the need for debugging during the lecture. This may have frustrated some students. Future iterations of this CURE delivered within this same course should be adapted to handle a wider range of previous experience with Python and coding handouts that are more compatible with different operating systems of students' computers. In addition, we could assign teams such that each team has sufficient experience with Python.

In future iterations of the CURE, we envision that we could provide students with sample data sets that they could use to refine and define their research question. This approach would have several benefits. First, there would be less time required to explain the collection of spatial data in the first lecture. This could enable more time for students to explore and understand the data provided to them, rather than collecting data themselves. Second, this approach would reduce the risks of compiler challenges and coding errors in the first lecture, which frustrated students. Finally, this approach would ensure that students have access to the relevant data and make this approach more resilient to changes in data availability. This last concern arose because, shortly after delivering Lecture 1, government websites removed some data sources that were needed for this CURE. By downloading data sources ahead of the CURE, we could ensure that students would have the required data needed to conduct their research.

Learning from the challenges we experienced during Lecture 1, we adapted the delivery of Lecture 2. After better understanding the student's coding capabilities, we simplified the examples that were delivered during the lecture. Further, we redesigned this lecture's coding handout so that students without prior experience in Python would be able to use Google Colab (a hosted Jupyter notebook that does not require any additional setup) to avoid issues with package management and version control. This resulted in far fewer compiling challenges during the lecture, and the instructor team was able to focus more on the concepts, as opposed to helping students debug code and resolve execution errors. As instructors, we were impressed by the speed with which students were able to understand and conceptualize the optimization models we presented.

In the future, we may need to adapt how each student's contributions are evaluated on each assignment. We observed that the majority of teams decided to split the workload by assigning one student to handle each assignment, rather than working together on all assignments. This resulted in a situation where one student did most of the data analysis, one student did more of the optimization modeling, and one student did more of the presentation. While this resulted in an equitable division of labor, we fear this approach did not enable all students to learn all of the desired skills. To address this, we may need to adapt how each assignment is evaluated and request that students report the extent of each member's contribution to the assignment.

6.2 Avenues for exploration for future IE/OR-focused CUREs

While our CURE had positive effects on self-reported research skills among students in the CURE section relative to the control section, we found that the attitudes towards engineering and career plans did not significantly differ among those in the CURE section compared to the control sections. We hypothesize that this is because many students who took this section of ISYE 3770 happened to be more senior students. These students' plans to participate in further undergraduate research experiences or to pursue additional courses in IE may have been less flexible compared to more junior students.

Therefore, an open question remains about which courses and students would be the best targets for IE-focused CUREs. For instance, one approach would be to deliver a similar CURE to sections of ISYE 3770 that are more likely to be taken by freshman or sophomore students. This approach may introduce non-IE majors to the field of IE earlier in their undergraduate careers, when their plans are more flexible. Further, some studies suggest that providing freshmen and sophomores with UREs is a promising avenue to induce excitement in STEM (Russell et al., 2007). However, because the students in this study are non-majors, they may not be as open to or interested in an IE-focused CURE. Another strategy would be to deliver this course in an advanced optimization course taken by more senior students who are IE majors. This approach could improve these students' access to UREs and may prepare these students for graduate school in IE. However, it may be that senior students will have already decided on post-graduation plans and thus be less flexible to adapt their career plans after the CURE.

Further, future exploration of CUREs in IE could seek which types of CURE have the most positive influence on attracting more students to seek careers or graduate education in IE. While the impacts may differ based on the academic stage of students, it would be valuable to understand what types of CUREs would provide the most benefits to different types of students. For example, perhaps for an upper-level optimization course, a CURE could be a more involved semester-long research project while for more junior students, a short course may be more beneficial.

Even though this CURE may not have had significant impacts on attracting students to IE, our findings suggest that the students in the CURE section were more familiar with what IE is and how to communicate IE concepts. These skills could potentially be beneficial as these students enter the workforce and collaborate with those working in IE. Future CUREs could examine the extent to which non-majors feel prepared to work with the IE workforce.

7 Conclusion

In this article, we presented a pilot study using a CURE to expose students in an undergraduate statistics course to open-ended questions in industrial engineering, focused on expanding access to services for certain populations. After the CURE, students reported positive gains in their level of experience with key research skills. There were also gains in the extent to which students viewed engineering problems as requiring creativity.

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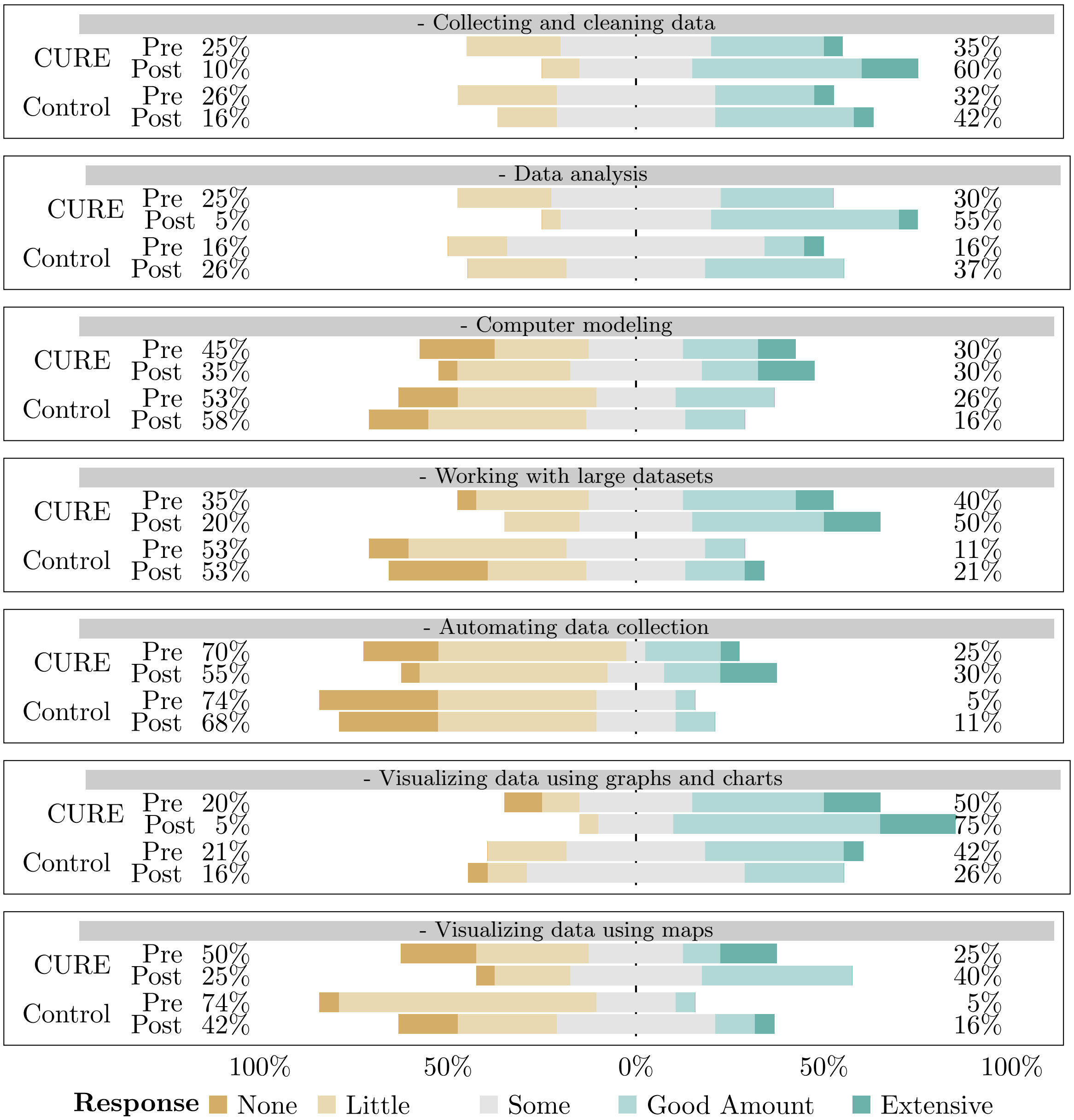


Figure 1: Answers to *indicate your experience with the following research skills*, shaded by student responses. "Pre" and "Post" indicate responses to the pre-course and post-course surveys, respectively. "CURE" indicates responses among students in the CURE section while "control" indicates responses among students who did not take the CURE section.

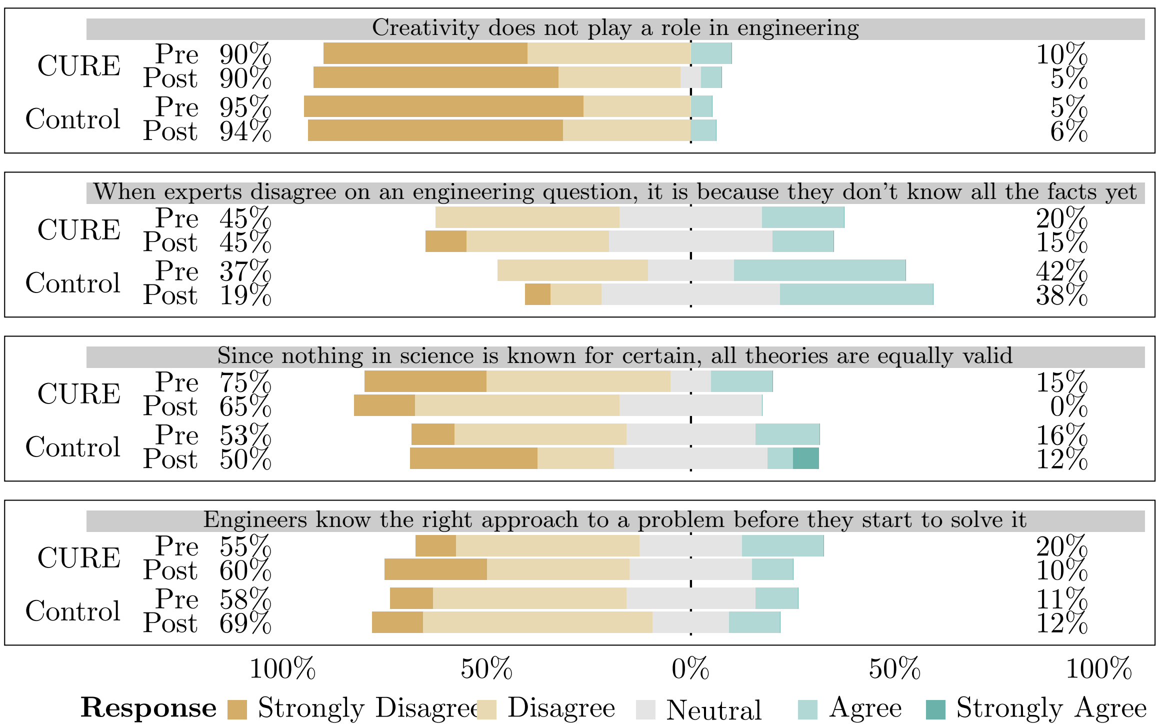


Figure 2: Answers to *indicate your agreement with the following statements*, shaded by student response. "Pre" and "Post" indicate responses to the pre-course and post-course surveys, respectively. "CURE" indicates responses among students in the CURE section while "control" indicates responses among students who did not take the CURE section. In all shown questions, CURE and control responses moved in opposite directions.

A Additional Demographic Data

Section(s)	CURE				Control			
Survey	Pre-Course		Post-Course		Pre-Course		Post-Course	
Enrolled at survey administration, n	63		59		224		209	
Responses, n (response rate)	37 (58.8%)		34 (57.6%)		81 (28.5%)		39 (13.7%)	
Reported Gender, n (%)								
Female	11	30%	8	24%	16	24%	13	36%
Male	21	57%	23	68%	21	31%	11	31%
Prefer not to say	-		1	3%	1	1%	-	
Not Reported	5	14%	2	6%	30	44%	12	33%
Reported Race, n (%)								
Asian/P.I.	20	54%	18	53%	14	21%	10	28%
Black	-		-		3	4%	2	6%
Hispanic / Latino	1	3%	2	6%	2	3%	2	6%
White	9	24%	8	24%	12	18%	9	25%
Asian/P.I.,White	1	3%	1	3%	2	3%	-	
Black,White	-		-		1	1%	-	
Hispanic / Latino,White	1	3%	2	6%	3	4%	-	
Prefer not to say	-		1	3%	1	1%	-	
Not Reported	5	14%	2	6%	30	44%	13	36%
International Student Status, n (%)								
Domestic student	27	73%	27	79%	35	51%	19	53%
International student	5	14%	5	15%	3	4%	4	11%
Not Reported	5	14%	2	6%	30	44%	13	36%
Parent Education Level, n (%)								
Some grade/high school	1	3%	3	9%	3	4%	2	6%
Completed high school or GED	1	3%	1	3%	2	3%	1	3%
Some college/technical school	2	5%	1	3%	6	9%	3	8%
Bachelor's degree	11	30%	10	29%	13	19%	6	17%
Some graduate/professional school	8	22%	7	21%	1	1%	1	3%
Completed graduate/professional school	9	24%	10	29%	13	19%	10	28%
Not Reported	5	14%	2	6%	30	44%	13	36%
Prior Semesters of College, n (%)								
1-2 semesters	2	5%	1	3%	5	7%	2	6%
3-4 semesters	5	14%	2	6%	14	21%	16	44%
5-6 semesters	17	46%	18	53%	14	21%	5	14%
More than 6 semesters	8	22%	11	32%	5	7%	-	
Not Reported	5	14%	2	6%	30	44%	13	36%
Remaining Semesters of College, n (%)								
1-2 semesters	25	68%	30	88%	12	18%	9	25%
3-4 semesters	4	11%	2	6%	21	31%	11	31%
5-6 semesters	3	8%	-		4	6%	1	3%
More than 6 semesters	-		-		1	1%	1	3%
Not Reported	5	14%	2	6%	30	44%	14	39%

Table 5: Complete demographic data from all respondents.

B Additional Results

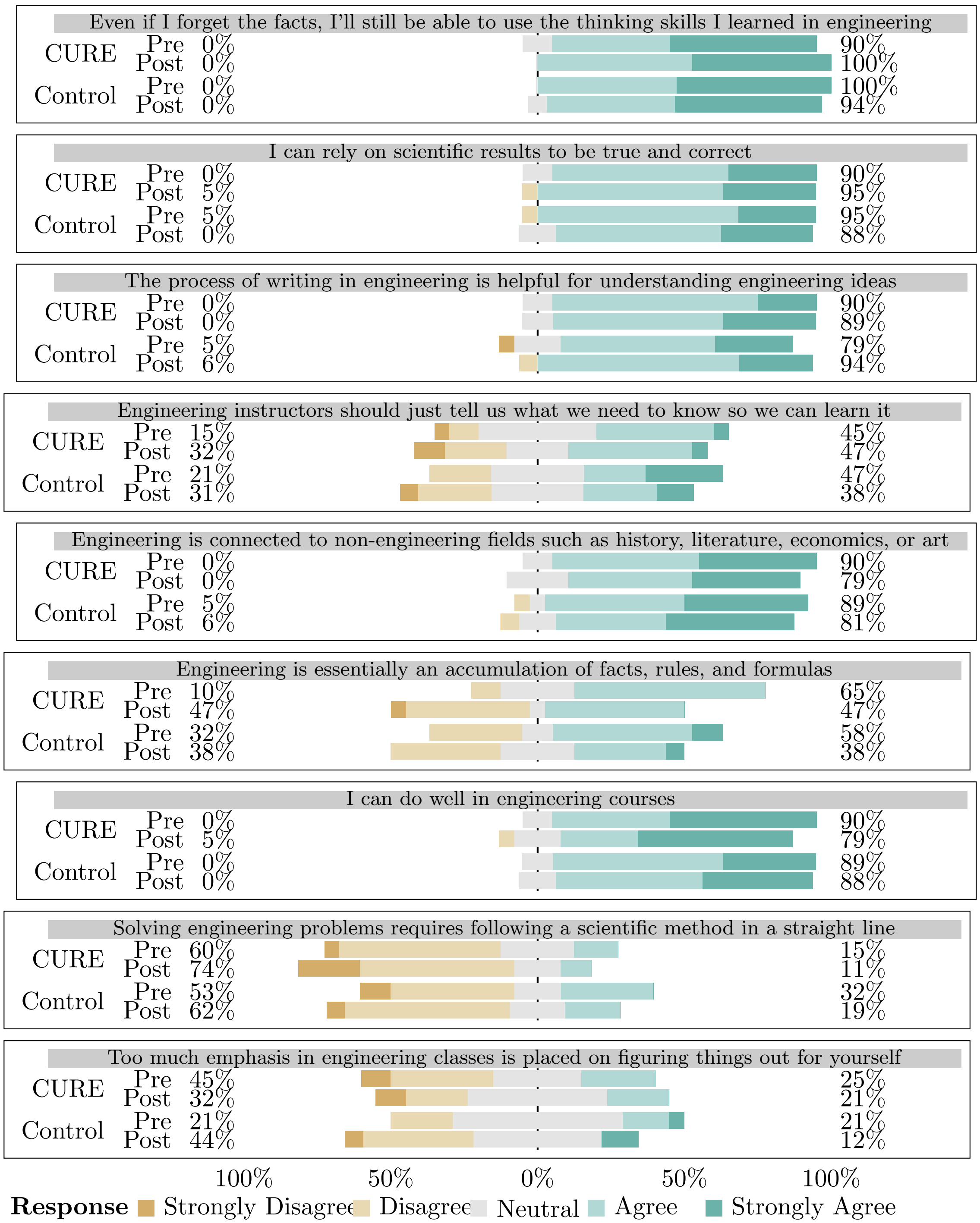


Figure 3: Further questions about student attitudes. Answers to *indicate your agreement with the following statements*.

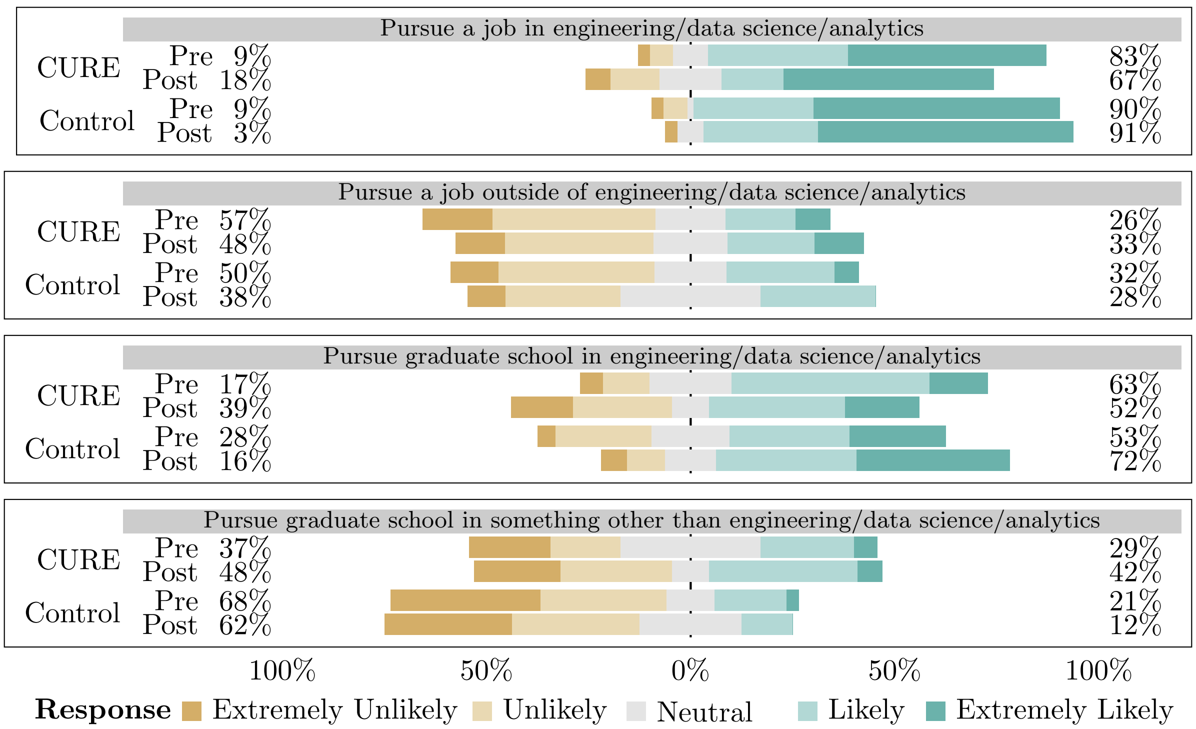


Figure 4: Answers to *following graduation, how likely are you to:*, "Pre" and "Post" indicate responses to the pre-course and post-course surveys, respectively. "CURE" indicates responses among students in the CURE section while "control" indicates responses among students who did not take the CURE section.

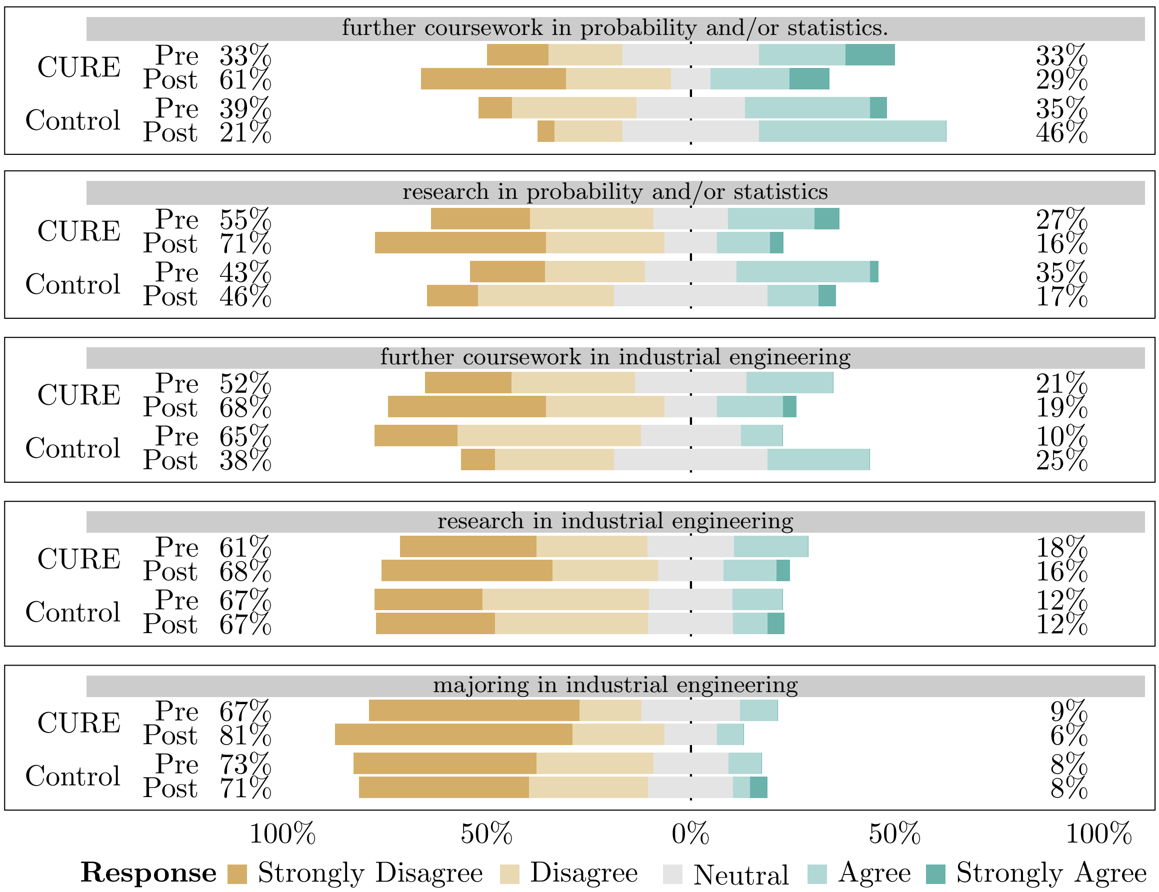


Figure 5: Answers to *indicate your agreement with the following statements: I am interested in ...*. "Pre" and "Post" indicate responses to the pre-course and post-course surveys, respectively. "CURE" indicates responses among students in the CURE section while "control" indicates responses among students who did not take the CURE section

C Presented Optimization Models

We use the shared sets, parameters, and decision variables in all of our models, as defined in table 6

	Sets
$\mathcal{F}$	the sinks capable of meeting
$\mathcal{O}$	the origins of demand in the network
	Parameters
d_o	the demand for services in the network
ℓ_{of}	the distance from o to f
c_f	the cost of adding services to f
	Decision Variables
y_f	Binary, 1 if f has services
x_{of}	Binary, 1 if o uses f

Table 6: Shared sets, parameters, and decision variables

Additionally, we formulate the following constraints, which we will use for each model:

$$\sum_{f \in \mathcal{F}} x_{of} = 1 \quad \forall o \in \mathcal{O} \tag{1}$$

$$\sum_{f \in \mathcal{F}} x_{of} \leq y_f \quad \forall f \in \mathcal{F}, o \in \mathcal{O} \tag{2}$$

Then we have the following models:

C.1 Average Distance Model

We first presented an model in which the DM was subject to a budget constraint of at most B and sought to minimize the total travel distance of all demand.

$$\begin{aligned} \underset{x,y}{\text{minimize}} \quad & \sum_{o \in \mathcal{O}} d_o \sum_{f \in \mathcal{F}} \ell_{of} x_{fo} \\ \text{subject to} \quad & (1) - (2), \\ & \sum_{f \in \mathcal{F}} c_f y_f \leq B \end{aligned}$$

C.2 Min-Max Model

We next presented a model in which the decision maker is subject to the same budget constraint, but now seeks to minimize the furthest distance that any demand must travel. To do this we introduce a new decision variable, z.

$$\begin{aligned} \underset{x,y,z}{\text{minimize}} \quad & z \\ \text{subject to} \quad & (1) - (2), \\ & \sum_{f \in \mathcal{F}} c_f y_f \leq B, \\ & z \geq \ell_{of} x_{of} \quad \forall\, o \in \mathcal{O}, f \in \mathcal{F} \end{aligned}$$

C.3 Set Cover Model

Then, we present a set covering model wherein the objective is to minimize the number of facilities we need to open so that we can provide service that is located no more than an acceptable length (l) from each demand. Let l denote this acceptable distance:

$$
\begin{aligned}
\underset{x,y}{\text{minimize}} \quad & \sum_{f \in \mathcal{F}} c_f y_f \\
\text{subject to} \quad & (1) - (2), \\
& \sum_{f \in \mathcal{F}} \ell_{of} x_{of} \leq l \quad \forall\, o \in \mathcal{O}
\end{aligned}
$$

C.4 Percentile-Set Covering

We then presented a model in which only a percentile of demand needed to be within the acceptable distance threshold. In addition to the acceptable distance l, we also define the target percentile as p. We introduce indicator variable u_o, which indicates if o is l close to a facility.

$$
\begin{aligned}
\underset{x,y,u}{\text{minimize}} \quad & \sum_{f \in \mathcal{F}} c_f y_f \\
\text{subject to} \quad & (1) - (2), \\
& \sum_{f \in \mathcal{F}} \ell_{of} x_{of} \leq l u_o \quad \forall\, o \in \mathcal{O}, \\
& \sum_{o \in \mathcal{O}} d_o u_o \geq p \sum_{o \in \mathcal{O}} d_o
\end{aligned}
$$

C.5 Maximal Covering Model

Lastly, we presented a model which constrains the number of facilities which can be opened while maximizing the population which is l-close to them.

$$
\begin{aligned}
\underset{x,y,u}{\text{maximize}} \quad & \sum_{o \in \mathcal{O}} d_o u_o \\
\text{subject to} \quad & (1) - (2), \\
& \sum_{f \in \mathcal{F}} c_f y_f \leq B, \\
& \sum_{f \in \mathcal{F}} \ell_{of} x_{of} \leq l u_o + M(1 - u_o) \quad \forall\, o \in \mathcal{O}
\end{aligned}
$$

D Assignments

D.1 Part 1: Existing Facility Locations and Demographic Data

Learning Objective: You will be able to collect appropriate data sources as inputs to classic optimization models.

D.1.1 Objectives:

1. Choose a specific service of interest .
2. Choose baseline demographic data and define population of interest.

Suggested Services of Interest: You are free to choose one of these or select a different service that aligns with your interests and the specific characteristics of your geographic context.

- **Food Services:** Restaurants, fast-food chains, grocery stores
- **Healthcare:** Hospitals, clinics, pharmacies
- **Recreation:** Parks and or sports facilities

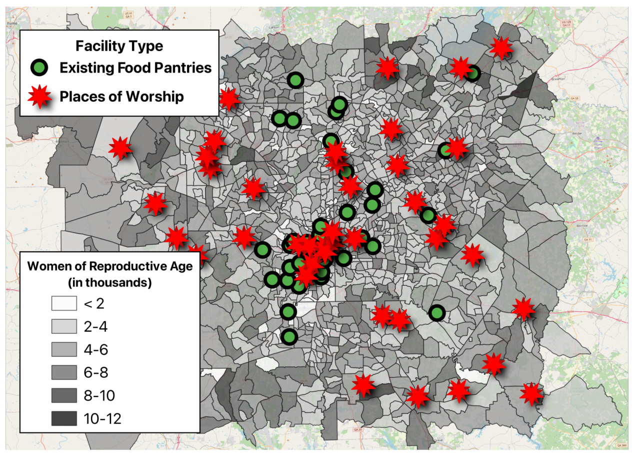
D.1.2 Tasks:

1. **Choose Your Service:** Select a service of interest from the list above or propose your own. Ensure it is relevant to your geographic context and has sufficient data (quantity and quality) available on OpenStreetMap or another source. There should be between 5 and 50 existing facilities.
2. **Define candidate expansions:** Consider how you will define new candidate facilities which do not currently provide your service but with some investment could either be built or modified to provide your service of interest. There should be between 5-50 candidate facilities.
3. **Get current (and candidate) facilities:**
   - **Adapt the Provided Code:** Customize the provided Python code to extract the specific data you need for your service of interest. See Files Project Jupyter Notebooks handout1.ipynb for details on this
   - **Data Format:** Ensure that your scraped data adheres to the specified format to pass the auto-grader. It should be projected into EPSG:3857 and be exported as a .gpkg file. Additionally, all of your facilities should be within the bounding box defined by [33.401638,34.191358,-83.839417,-84.992981] for Atlanta, Georgia
   - **Data Quality:** Check the quality of your scraped data. Remove any inconsistencies or errors.
4. **Get preliminary demographic data:**
   - **Brainstorm** what demographic group would be most relevant for your service of interest using American Community Survey to find available data
   - **Choose** the resolution of your data, are you going to look at census tracts, county subdivisions, or block-groups? This will depend on data availability for your demographic data.

- **Adapt the provided code** to gather your selected variables using the 'census' package in python
- **Submit** *gpkg* which contains details about the demographic data that you are using. *origins.gpkg* should be a saved geopandas data frame. Each row should have a polygon as its geometry and at a minimum a 'population' attribute.

5. **Visualize existing facilities and populations:** Generate a set of two maps, with polygons indicating your demographic data and points illustrating the placement of facilities. Your map should have the following attributes:
   - **Demographic data** – colored by the 'population' attribute
   - **Facilities** – colored by their 'existing' attribute
   - **A legend** – no points will be awarded without a legend.

Below is an example which would give you full credit:



D.1.3 Assessment:

You will be assessed on both the quality and correctness of your data (using an auto grader worth 80%) and the quality of your visualization (using a human grader worth 20%). You will turn in three files a *facilities.gpkg* file, an *origins.gpkg* file and a *map.png* file.

Auto grader Rubric: Your .gpkg file will be assessed against the following auto-grader rubric, with each row indicating a unit test that we will run against your .gpkg file. Either complete points or no points will be given for each item. You can see the score that you will receive in gradescope. You will have to build on your submission in later parts of the project, so please do your best to get full marks here.

Human Grader Rubric: You must have a legend on your map, without one no points will be awarded.

Criteria	Points:
Correct Facility Quantity (*facilities.gpkg)*	
5-50 existing facilities, indicated by 'existing' == 1	0.1
5-50 candidate facilities, indicated by 'existing' == 0	0.1
Demographic Data *(origins.gpkg)*	
500-3000 polygons in in *origins.gpkg*	0.1
Column 'population' present in geodf	0.1
Spatial Accuracy and Projection	
CRS is set to EPSG:3857	0.1
All facilities within the designated boundary	0.1
Data Quality	
Correct (point and polygon) geometries	0.1
No errors or other inconsistencies	0.1
Total	**0.8**

Criteria	Points:
Facilities are present and colored by 'existing' status	0.1
Demographic data are present and colored by	0.1

D.2 Assignment 2: Access to Services and Optimization Models

Learning Objective: Apply a mathematical models to evaluate current access to services

D.2.1 Objectives:

- Generate a distribution of travel distances to your current service of interest.
- Apply two optimization models covered in class to your scenario of instance.
- Generate travel distance distributions for each selected optimization model

D.2.2 Tasks:

- **Adapt the code** from handout2.ipynb to read in the facilities.gpkg and origins.gpkg files you uploaded for your first
- **Generate a distance matrix** from each origin (rows) to each facilities (columns)
- Use the distance matrix to **evaluate current travel distances** to existing service locations
- Apply **two different optimization** models covered in class to your data
  - For each model's results, add a column to the facilities indicating its status
  - Please follow the following naming conventions:
    1. For an average distance model with p additional facilities: ad_{p}
    2. For a min-max model with p additional facilities: mm_{p}
    3. For a set covering model with an acceptable distance of d: sc_{d}, if d is no integer, use a . to separate the decimal: d = 36.5 has a name of sc_36.5

4. For a quantile set covering model with an acceptable distance of d and quantile of q: qsc_{d}_{100*q}. Use the same notation as above for decimals. If d = 10 and q = 0.75 , the appropriate name is qsc_10_75
5. For a maximal cover model, with p additional facilities and d acceptable distance threshold: mc_{p}-{d}

   – Add the column status_{MODEL_NAME} to your facilities data frame for each selected optimization model.

- Generate distributions of travel distances under each selected optimization model Follow the naming conventions outlined above, adding dist_{MODEL_NAME} to your origins data frame for each selected optimization model.
- Use your generated distribution to **visualize the impact of optimization models** via histograms.

D.2.3 Assessment:

You will be assessed on the **correctness** of your travel-time estimates as well as the **clarity** of your visuals. You will turn in three files.

D.2.4 Deliverables:

NOTE: *if you did not receive full credit on part 1 and have not modified your submission before part 2, you will not receive full credit on part 2. Please correct your mistakes before submitting so that you are not doubly penalized.*

- ***facilities.gpkg*** - a .gpkg file that contains service facilities and their existing status, additionally, you must have two new columns:
  - status_{MODEL_1_NAME} – a binary vector (0,1) indicating if a particular facility has your service of interest under Replace MODEL_1_NAME with an appropriate name
  - status_{ MODEL_2_NAME } – a binary vector (0,1) indicating if a particular facility has your service of interest under Replace MODEL_2_NAME with an appropriate name
- ***origins.gpkg*** - a .gpkg file containing the origins with weights given by a column 'populations' additionally, you must have three new columns:
  - dist_baseline - the minimum travel distance from each origin to an existing facility
  - dist_{ MODEL_1_NAME } – the minimum travel distance from each origin to a facility that has your service of interest after solving optimization model replace MODEL_1_NAME with an appropriate name
  - dist_{ MODEL_2_NAME } – the minimum travel distance from each origin to a facility that has your service of interest after solving optimization model replace MODEL_2_NAME with an appropriate name

a .png histogram with two plots showing the distribution of travel distances at baseline and under the system expansions proposed by your two chosen optimization models. To receive full credit, the following must be true:

- The x-axis should be the travel distance in miles.

Criteria	**Points:**
Data Quality Facilities	
CRS is set to EPSG:3857 for facilities	0.1
CRS is set to EPSG:3857 for origins	0.1
Correctness of Baseline Distance	
Baseline travel distances are completely correctly calculated	0.1
50% of baseline_dists are calculated correctly (within 1/10 of a mile)	0.1
75% of travel distances are calculated correctly (within 1/25$^{\text{th}}$ of a mile)	0.1
95% of travel distances are calculated correctly (within 1/50$^{\text{th}}$ of a mile)	0.1
Optimization Model 1	
dist_{ MODEL_1_NAME } is present in the origins DF	0.1
status_{ MODEL_1_NAME } is present in the facility DF	0.1
dist_{ MODEL_1_NAME } is correctly calculated from status_{ MODEL_1_NAME}	0.1
Optimization Model 2	
dist_{ MODEL_2_NAME } is present in the origins dataframe	0.1
status_{ MODEL_2_NAME } is present in the facility DF	0.1
dist_{ MODEL_2_NAME } is correctly calculated from status_{ MODEL_2_NAME}	0.1
Total	1.2

Criteria	Points:
Baseline distance is plotted in both figures	0.1
MODEL_1 is plotted with appropriate color	0.1
MODEL_2 is plotted with appropriate color	0.1
Total	0.3

- The axis should be the number of individuals from your population
- your figure must have a legend and should use color to clearly differentiate between baseline distances and your chosen optimization model.

The image below is included as an example of a plot that would receive full credit.

D.2.5 Auto-Grading

Your *facilities.gpkg* and *origins.gpkg* files will be assessed against the following auto grader rubric, with each row indicating a unit test that we will run against the files you provide. Either complete points or no points will be given for each item, no partial credit will be awarded .

D.2.6 Human Grader Rubric:

You must have legends on your histograms, without one no points will be awarded.

D.3 Assignment 3: Presentation

On April 21st, we will break up into groups of 3-4 teams and each team will present to their (smaller) group. You will have 12 minutes to present in total, with 8-10 minutes devoted to your presentation and 2-4 minutes of questions. Your peers will review your presentation, and your grade for this part will be based on their ratings. We recommend following roughly with the below outline:

- Introduction (2) slides: clearly state your problem and the relevant stakeholders
- Data Sources (1) slide: where did you get your data? What data are you using?
- Proposed Expansions (2) slides: state what models you are using and why you chose each model
- Discussion (1-2) slides: compare your models with the baseline and each other, state trends
- Conclusion (1-2) slides: what conclusions could a decision maker take from your work? If you wanted to expand your work, in what direction would you go?

This is an opportunity to be creative in how you choose to present your findings! We encourage you to think about the story you want to tell and how you can use your statistical findings to support your narrative. We've attached a few resources that we have found helpful when designing slides:

- Jean Luc Doumont: Creating Effective Slides
- Susan McConnel: Designing Effective Scientific Presentations
- MIT Communications Lab: Technical Presentation

Please turn in your slides in advance of presenting. **This assignment is due before class.**

D.4 Assignment 4: Executive Summary

You are expected to turn in a written summary of your project. We believe that 3-4 pages, with figures included, is an appropriate length with which to concisely summarize your project. There is a template available `Written_Report_Template.docx` which includes all necessary sections. Your content should be similar to your presentation:

- **Introduction** in which you identify your problems and relevant stakeholders and also detail what makes your research question a worthwhile one to ask.
- **Data Sources** where you should clearly state what data you are using and from where you acquired it.
- **Proposed Expansions** where you talk about both of your models. You should include enough detail so that an expert in your problem would know exactly what each proposed expansion would achieve. Please also include appropriate summary statistics for each model.
- **Discussion** in which you should compare each model to the others and summarize any trends you observe from either a spatial or a population level. Here is a good place to include 1 or 2 relevant figures.
- **Conclusion** should have two components. Firstly, you should state if you had to recommend a single policy, what policy you would recommend and why you would recommend it. Secondly, you should include a future work / limitations section describing how your model is limited.

See `Written_Report_Example.docx` for a written report with the food pantry data presented in class. If you have any questions or run into problems plotting your data, please reach out via email or teams in advance of the deadline!

E Survey Instruments

E.1 Pre-Course Survey Instrument

ISYE 3770 Pre-Course Survey

Survey Flow

Block: Block 0: Confirming 18 years or older (1 Question)
Standard: Block 1: Consent (1 Question)
Standard: Block 2: Respondent Information (1 Question)
Standard: Block 3: Career Goals and Ambitions (5 Questions)
Standard: Block 4: Prior Experience with Course Elements (3 Questions)
Standard: Block 5: Attitudes towards engineering (1 Question)
Standard: Block 6 (3 Questions)
Standard: Block 7: Knowledge of Industrial Engineering (5 Questions)
Standard: Block 8: More respondent information (7 Questions)

Page Break

Start of Block: Block 0: Confirming 18 years or older

Q2 Are you at least 18 years old?

◯ Yes (1)

◯ No (2)

Skip To: End of Survey If Q2 = No

End of Block: Block 0: Confirming 18 years or older

Start of Block: Block 1: Consent

Q3 You are being asked to be a volunteer in a research study. The purpose of this study is to understand the pedagogical value of a course-based undergraduate research experience (CURE) as an application-focused introduction to Industrial Engineering (IE). Depending on your course section, you will participate in CURE and submit the associated assignments as part of ISYE 3770 even if you do not consent to participate in the study. Your decision to participate in the study will not affect your grade or standing in the class. Please note that this survey is best taken on a device that has a screen the size of a tablet or larger. If you consent to participating in the research study, you will be asked to submit two surveys about your attitude towards and knowledge of IE. The surveys will each take approximately 15 minutes to complete. No personally identifiable information, such as your name and email will be gathered. However, we ask for the last four digits of your phone number. This will be used to link your pre-course and post-course survey responses and deleted immediately following linkage. Your identifiable information will be visible only to the primary investigator. The risks involved are no greater than those involved in daily activities. You will not benefit or be compensated for joining this study. We will comply with any applicable laws and regulations regarding confidentiality. To make sure that this research is being carried out in the proper way, the Georgia Institute of Technology IRB may review study records. The Office of Human Research Protections may also look at study records. If you have any questions about the study, you may contact Dr. Lauren Steimle by email at steimle@gatech.edu. If you have any questions about your rights as a research subject, you may contact Georgia Institute of Technology Office of Research Integrity Assurance at IRB@gatech.edu. Thank you for participating in this study. By completing the online survey, you indicate your consent to be in the study.

◯ Agree to be in the study (1)

◯ Disagree (2)

Skip To: End of Survey If Q3 = Disagree

End of Block: Block 1: Consent

Start of Block: Block 2: Respondent Information

*

Q4 Please type the last four digits of your phone number. This information will be used confidentially to match pre-course data to post-course data by the researchers and will not be shared with the instructor of ISYE 3770.

____

End of Block: Block 2: Respondent Information

Start of Block: Block 3: Career Goals and Ambitions

Q5 Have you declared a major yet?

- Yes (1)
- No (2)

Display This Question:

If Q5 = Yes

Q6 Which major have you declared?

____

Display This Question:

If Q5 = No

Q7 How likely are you to major in industrial engineering?

- ◯ Extremely unlikely (1)
- ◯ Somewhat unlikely (2)
- ◯ Neither likely nor unlikely (3)
- ◯ Somewhat likely (4)
- ◯ Extremely likely (5)

Display This Question:

If Q5 = No

Q8 How likely are you to major in another data science/analytics-focused degree (e.g., computer science, mathematics)?

- ◯ Extremely unlikely (1)
- ◯ Somewhat unlikely (2)
- ◯ Neither likely nor unlikely (3)
- ◯ Somewhat likely (4)
- ◯ Extremely likely (5)

Q9 Please indicate how likely you are to do each of the following in the first year after graduation:

	Extremely unlikely (1)	Somewhat unlikely (2)	Neither likely nor unlikely (3)	Somewhat likely (4)	Extremely likely (5)
Pursue a job in engineering/data science/analytics (1)	○	○	○	○	○
Pursue a job outside of engineering/data science/analytics (2)	○	○	○	○	○
Pursue graduate school in engineering/data science/analytics (3)	○	○	○	○	○
Pursue graduate school in something other than engineering/data science/analytics (4)	○	○	○	○	○

End of Block: Block 3: Career Goals and Ambitions

Start of Block: Block 4: Prior Experience with Course Elements

Q10 **Please look over this inventory of elements that may be included in this course.** For each element, give an estimate of your experience before the course begins. Your current level of experience may be a result of courses in high school or college, or it may be a result of other experiences such as jobs or special programs. What is your level experience with the following **working styles**?

	No experience (1)	Little experience (2)	Some Experience (3)	A good amount of experience (4)	Extensive experience (5)	N/A (6)
Working individually (1)	○	○	○	○	○	○
Working in small groups (2)	○	○	○	○	○	○
Becoming responsible for part of a project (3)	○	○	○	○	○	○

Q11 What is your level experience with the following **research skills**?

	No experience (1)	Little experience (2)	Some experience (3)	A good amount of experience (4)	Extensive experience (5)
Collecting and cleaning data (1)	○	○	○	○	○
Data analysis (2)	○	○	○	○	○
Computer modeling (3)	○	○	○	○	○
Working with large datasets (4)	○	○	○	○	○
Automating data collection (5)	○	○	○	○	○
Visualizing data using graphs and charts (6)	○	○	○	○	○
Visualizing data using maps (7)	○	○	○	○	○

Q12 What is your level experience with the following **presentation skills**?

	No experience (1)	Little experience (2)	Some experience (3)	A good amount of experience (4)	Extensive experience (5)
Presenting results orally (1)	○	○	○	○	○
Presenting results in written papers or reports (2)	○	○	○	○	○
Critiquing the work of other students (3)	○	○	○	○	○

End of Block: Block 4: Prior Experience with Course Elements

Start of Block: Block 5: Attitudes towards engineering

Q13 Please rate your agreement with the following items:

	Strongly disagree (1)	Somewhat disagree (2)	Neither agree nor disagree (3)	Somewhat agree (4)	Strongly agree (5)
Even if I forget the facts, I'll still be able to use the thinking skills I learned in engineering (1)	○	○	○	○	○
I can rely on scientific results to be true and correct (2)	○	○	○	○	○
The process of writing in engineering is helpful for understanding engineering ideas (3)	○	○	○	○	○
Engineering instructors should just tell us what we need to know so we can learn it (4)	○	○	○	○	○
Creativity does not play a role in engineering (5)	○	○	○	○	○
Engineering is connected to non-engineering fields such as history, literature, economics, or art (6)	○	○	○	○	○

When experts disagree on an engineering question, it is because they don’t know all the facts yet (7)	○	○	○	○	○
Since nothing in science is known for certain, all theories are equally valid (8)	○	○	○	○	○
Engineering is essentially an accumulation of facts, rules, and formulas (9)	○	○	○	○	○
I can do well in engineering courses (10)	○	○	○	○	○
Solving engineering problems requires following a scientific method in a straight line (11)	○	○	○	○	○
Too much emphasis in engineering classes is placed on figuring things out for yourself (12)	○	○	○	○	○
Engineers know the right approach to a problem	○	○	○	○	○

before they start to solve it (13)

End of Block: Block 5: Attitudes towards engineering

Start of Block: Block 6

Q14 Please rate your level of agreement with the following statements about **transferable skills:**

	Strongly disagree (1)	Somewhat disagree (2)	Neither agree nor disagree (3)	Somewhat agree (4)	Strongly agree (5)
I can model real world processes with appropriate random variables (1)	○	○	○	○	○
I can identify appropriate statistical analyses to answer questions about real world problems (2)	○	○	○	○	○
I can recognize when mathematical modeling is appropriate to solve a problem (3)	○	○	○	○	○
I can communicate findings of a statistical analysis to an audience of non-specialists. (4)	○	○	○	○	○
I can communicate findings from a mathematical model to an audience of non-specialists.	○	○	○	○	○

(5)

Q15 Please rate your level of agreement with the following statements about **industrial engineering as a field.**

	Strongly disagree (1)	Somewhat disagree (2)	Neither agree nor disagree (3)	Somewhat agree (4)	Strongly agree (5)
I know what industrial engineers do (1)	○	○	○	○	○
Industrial engineering concepts are relevant to my life (2)	○	○	○	○	○
Industrial engineering can improve people's lives (3)	○	○	○	○	○

Q16 Please rate your level of agreement with the following statements about **your interests**.

	Strongly disagree (1)	Somewhat disagree (2)	Neither agree nor disagree (3)	Somewhat agree (4)	Strongly agree (5)
I am interested in pursuing further coursework in probability and/or statistics. (1)	○	○	○	○	○
I am interested in pursuing research in probability and/or statistics (2)	○	○	○	○	○
I am interested in pursuing further coursework in industrial engineering (3)	○	○	○	○	○
I am interested in pursuing research in industrial engineering (4)	○	○	○	○	○
I am interested in majoring in industrial engineering (5)	○	○	○	○	○

End of Block: Block 6

Start of Block: Block 7: Knowledge of Industrial Engineering

Q20 Below are three questions with free-text response. Please write as much or as little as you see appropriate. If you are unable to answer a question, please write that.

Q17 How would you describe the field of industrial engineering?

____

____

____

____

____

Q18 What interests you about industrial engineering?

____

Q19 What are the most important skills for industrial engineers to possess?

____

Q21 If you plan to major in something other than industrial engineering, in what ways do you expect industrial engineering to relate to your intended field of study? (Please leave blank if you plan to major in industrial engineering).

____

End of Block: Block 7: Knowledge of Industrial Engineering

Start of Block: Block 8: More respondent information

Q22 Please tell us a bit about yourself. Your responses will help put your answers in context.

Q21 What is your gender?

- ○ Male (1)
- ○ Female (2)
- ○ Non-binary (3)
- ○ Other: (4) ____
- ○ Prefer not to say (5)

Q23 How would you describe yourself? Please check ALL that apply to you.

- ▢ Asian/Pacific Islander (1)
- ▢ Black (2)
- ▢ Hispanic / Latino (3)
- ▢ Native American (4)
- ▢ White/ Caucasian (5)
- ▢ Other (please specify) (6) ____
- ▢ Prefer not to say (7)

Q24 Prior to this semester, how many semesters of college study did you have? Please exclude semesters you've spent on co-op.

- 1-2 semesters (1)
- 3-4 semesters (2)
- 5-6 semesters (3)
- More than 6 semesters (4)

Q25 How many semesters of study do you anticipate remaining before your graduation? Again, please exclude semesters you might spend on co-op.

- 1-2 semesters (1)
- 3-4 semesters (2)
- 5-6 semesters (3)
- More than 6 semesters (4)

Q26 What is your domestic/international student status?

- Domestic student (1)
- International student (2)

Q27 What is your parents' highest level of education?

- ○ Some grade/high school (1)
- ○ Completed high school or GED (2)
- ○ Some college/technical school (3)
- ○ Bachelor's degree (4)
- ○ Some graduate/professional school (5)
- ○ Completed graduate/professional school degree(s) (6)

End of Block: Block 8: More respondent information

E.2 Post-Course Survey Instrument

ISYE 3770 Post-Course Survey

Survey Flow

Block: Block 0: Confirming 18 years or older (1 Question)
Standard: Block 1: Consent (1 Question)
Standard: Block 2: Respondent Information (1 Question)
Standard: Block 3: Career Goals and Ambitions (5 Questions)
Standard: Block 4: Prior Experience with Course Elements (3 Questions)
Standard: Block 5: Attitudes towards engineering (1 Question)
Standard: Block 6 (3 Questions)
Standard: Block 7: Knowledge of Industrial Engineering (6 Questions)
Standard: Block 8: More respondent information (7 Questions)

Page Break

Start of Block: Block 0: Confirming 18 years or older

Q2 Are you at least 18 years old?

○ Yes (1)

○ No (2)

Skip To: End of Survey If Q2 = No

End of Block: Block 0: Confirming 18 years or older

Start of Block: Block 1: Consent

Q3 You are being asked to be a volunteer in a research study. The purpose of this study is to understand the pedagogical value of a course-based undergraduate research experience (CURE) as an application-focused introduction to Industrial Engineering (IE). Depending on your course section, you will participate in CURE and submit the associated assignments as part of ISYE 3770 even if you do not consent to participate in the study. Your decision to participate in the study will not affect your grade or standing in the class. Please note that this survey is best taken on a device that has a screen the size of a tablet or larger. If you consent to participating in the research study, you will be asked to submit two surveys about your attitude towards and knowledge of IE. The surveys will each take approximately 15 minutes to complete. No personally identifiable information, such as your name and email will be gathered. However, we ask for the last four digits of your phone number. This will be used to link your pre-course and post-course survey responses and deleted immediately following linkage. Your identifiable information will be visible only to the primary investigator. The risks involved are no greater than those involved in daily activities. You will not benefit or be compensated for joining this study. We will comply with any applicable laws and regulations regarding confidentiality. To make sure that this research is being carried out in the proper way, the Georgia Institute of Technology IRB may review study records. The Office of Human Research Protections may also look at study records. If you have any questions about the study, you may contact Dr. Lauren Steimle by email at steimle@gatech.edu. If you have any questions about your rights as a research subject, you may contact Georgia Institute of Technology Office of Research Integrity Assurance at IRB@gatech.edu. Thank you for participating in this study. By completing the online survey, you indicate your consent to be in the study.

○ Agree to be in the study (1)

○ Disagree (2)

Skip To: End of Survey If Q3 = Disagree

End of Block: Block 1: Consent

Start of Block: Block 2: Respondent Information

*

Q4 Please type the last four digits of your phone number. This information will be used confidentially to match pre-course data to post-course data by the researchers and will not be shared with the instructor of ISYE 3770. Last 4 digits of your phone number:

____

End of Block: Block 2: Respondent Information

Start of Block: Block 3: Career Goals and Ambitions

Q5 Have you declared a major yet?

○ Yes (1)

○ No (2)

- -

Display This Question:

If Q5 = Yes

Q6 Which major have you declared?

____

- -

Display This Question:

If Q5 = No

Q7 How likely are you to major in industrial engineering?

- Extremely unlikely (1)
- Somewhat unlikely (2)
- Neither likely nor unlikely (3)
- Somewhat likely (4)
- Extremely likely (5)

Display This Question:

If Q5 = No

Q8 How likely are you to major in another data science/analytics-focused degree (e.g., computer science, mathematics)?

- Extremely unlikely (1)
- Somewhat unlikely (2)
- Neither likely nor unlikely (3)
- Somewhat likely (4)
- Extremely likely (5)

Q9 Please indicate how likely you are to do each of the following after graduation:

	Extremely unlikely (1)	Somewhat unlikely (2)	Neither likely nor unlikely (3)	Somewhat likely (4)	Extremely likely (5)
Pursue a job in engineering/data science/analytics (1)	○	○	○	○	○
Pursue a job outside of engineering/data science/analytics (2)	○	○	○	○	○
Pursue graduate school in engineering/data science/analytics (3)	○	○	○	○	○
Pursue graduate school in something other than engineering/data science/analytics (4)	○	○	○	○	○

End of Block: Block 3: Career Goals and Ambitions

Start of Block: Block 4: Prior Experience with Course Elements

Q10 **Please look over this inventory of elements some of which were included in this course.** For each element, give an estimate of your experience before the course begins. Your current level of experience may be a result of courses in high school or college, or it may be a result of other experiences such as jobs or special programs. What is your level experience with the following **working styles**?

	No experience (1)	Little experience (2)	Some Experience (3)	A good amount of experience (4)	Extensive experience (5)	N/A (6)
Working individually (1)	○	○	○	○	○	○
Working in small groups (2)	○	○	○	○	○	○
Becoming responsible for part of a project (3)	○	○	○	○	○	○

Q11 What is your level experience with the following **research skills**?

	No experience (1)	Little experience (2)	Some experience (3)	A good amount of experience (4)	Extensive experience (5)
Collecting and cleaning data (1)	○	○	○	○	○
Data analysis (2)	○	○	○	○	○
Computer modeling (3)	○	○	○	○	○
Working with large datasets (4)	○	○	○	○	○
Automating data collection (5)	○	○	○	○	○
Visualizing data using graphs and charts (6)	○	○	○	○	○
Visualizing data using maps (7)	○	○	○	○	○

Q12 What is your level experience with the following **presentation skills**?

	No experience (1)	Little experience (2)	Some experience (3)	A good amount of experience (4)	Extensive experience (5)
Presenting results orally (1)	○	○	○	○	○
Presenting results in written papers or reports (2)	○	○	○	○	○
Critiquing the work of other students (3)	○	○	○	○	○

End of Block: Block 4: Prior Experience with Course Elements

Start of Block: Block 5: Attitudes towards engineering

Q13 Please rate your agreement with the following items:

	Strongly disagree (1)	Somewhat disagree (2)	Neither agree nor disagree (3)	Somewhat agree (4)	Strongly agree (5)
Even if I forget the facts, I'll still be able to use the thinking skills I learned in engineering (1)	○	○	○	○	○
I can rely on scientific results to be true and correct (2)	○	○	○	○	○
The process of writing in engineering is helpful for understanding engineering ideas (3)	○	○	○	○	○
Engineering instructors should just tell us what we need to know so we can learn it (4)	○	○	○	○	○
Creativity does not play a role in engineering (5)	○	○	○	○	○
Engineering is connected to non-engineering fields such as history, literature, economics, or art (6)	○	○	○	○	○

When experts disagree on an engineering question, it is because they don’t know all the facts yet (7)	○	○	○	○	○
Since nothing in science is known for certain, all theories are equally valid (8)	○	○	○	○	○
Engineering is essentially an accumulation of facts, rules, and formulas (9)	○	○	○	○	○
I can do well in engineering courses (10)	○	○	○	○	○
Solving engineering problems requires following a scientific method in a straight line (11)	○	○	○	○	○
Too much emphasis in engineering classes is placed on figuring things out for yourself (12)	○	○	○	○	○
Engineers know the right approach to a problem	○	○	○	○	○

before they start to solve it (13)	

End of Block: Block 5: Attitudes towards engineering

Start of Block: Block 6

Q14 Please rate your level of agreement with the following statements about **transferable skills:**

	Strongly disagree (1)	Somewhat disagree (2)	Neither agree nor disagree (3)	Somewhat agree (4)	Strongly agree (5)
I can model real world processes with appropriate random variables (1)	○	○	○	○	○
I can identify appropriate statistical analyses to answer questions about real world problems (2)	○	○	○	○	○
I can recognize when mathematical modeling is appropriate to solve a problem (3)	○	○	○	○	○
I can communicate findings of a statistical analysis to an audience of non-specialists. (4)	○	○	○	○	○
I can communicate findings from a mathematical model to an audience of non-specialists.	○	○	○	○	○

(5)

Q15 Please rate your level of agreement with the following statements about **industrial engineering as a field.**

	Strongly disagree (1)	Somewhat disagree (2)	Neither agree nor disagree (3)	Somewhat agree (4)	Strongly agree (5)
I know what industrial engineers do (1)	○	○	○	○	○
Industrial engineering concepts are relevant to my life (2)	○	○	○	○	○
Industrial engineering can improve people's lives (3)	○	○	○	○	○

Q16 Please rate your level of agreement with the following statements about **your interests**.

	Strongly disagree (1)	Somewhat disagree (2)	Neither agree nor disagree (3)	Somewhat agree (4)	Strongly agree (5)
I am interested in pursuing further coursework in probability and/or statistics. (1)	○	○	○	○	○
I am interested in pursuing research in probability and/or statistics (2)	○	○	○	○	○
I am interested in pursuing further coursework in industrial engineering (3)	○	○	○	○	○
I am interested in pursuing research in industrial engineering (4)	○	○	○	○	○
I am interested in majoring in industrial engineering (5)	○	○	○	○	○

End of Block: Block 6

Start of Block: Block 7: Knowledge of Industrial Engineering

Q20 Below are three questions with free-text response. Please write as much or as little as you see appropriate. If you are unable to answer a question, please write that.

Q17 How would you describe the field of industrial engineering?

Q18 What interests you about industrial engineering?

Q19 What are the most important skills for industrial engineers to possess?

Q21 If you plan to major in something other than industrial engineering, in what ways do you expect industrial engineering to relate to your intended field of study? (Please leave blank if you plan to major in industrial engineering).

Q29 In your own words, how has your understanding of industrial engineering changed this semester?

____

____

____

End of Block: Block 7: Knowledge of Industrial Engineering

Start of Block: Block 8: More respondent information

Q22 Please tell us a bit about yourself. Your responses will help put your answers in context.

Q21 What is your gender?

- ○ Male (1)
- ○ Female (2)
- ○ Non-binary (3)
- ○ Other: (4) ____
- ○ Prefer not to say (5)

Q23 How would you describe yourself? Please check ALL that apply to you.

- Asian/Pacific Islander (1)
- Black (2)
- Hispanic / Latino (3)
- Native American (4)
- White/ Caucasian (5)
- Other (please specify) (6) ____
- Prefer not to say (7)

Q24 Prior to this semester, how many semesters of college study did you have? Please exclude semesters you've spent on co-op.

- 1-2 semesters (1)
- 3-4 semesters (2)
- 5-6 semesters (3)
- More than 6 semesters (4)

Q25 How many semesters of study do you anticipate remaining before your graduation? Again, please exclude semesters you might spend on co-op.

- 1-2 semesters (1)
- 3-4 semesters (2)
- 5-6 semesters (3)
- More than 6 semesters (4)

Q26 What is your domestic/international student status?

- Domestic student (1)
- International student (2)

Q27 What is your parents' highest level of education?

- Some grade/high school (1)
- Completed high school or GED (2)
- Some college/technical school (3)
- Bachelor's degree (4)
- Some graduate/professional school (5)
- Completed graduate/professional school degree(s) (6)

End of Block: Block 8: More respondent information