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Work-In-Progress: Engineering Self-Efficacy in First-Year Design

Megan Gray, Duke University

Megan Gray is a Research Analyst in Evaluation and Engagement at Duke University's Social Science Research Institute (SSRI). She serves as a project manager and researcher for both qualitative and quantitative evaluation and research efforts, in partnership with community-based programs as well as campus-based initiatives. Megan came to Duke from the nonprofit field, where she evaluated and monitored implementation of county-wide early childhood programs. Her prior experience includes school-based social work, teen pregnancy prevention/positive youth development programming, and public health evaluation.

Dr. Ann Saterbak, Duke University

Ann Saterbak is Professor of the Practice in the Biomedical Department and Director of First-Year Engineering at Duke University. Saterbak is the lead author of the textbook, Bioengineering Fundamentals. Saterbak's outstanding teaching was recognized through university-wide and departmental teaching awards. In 2013, Saterbak received the ASEE Biomedical Engineering Division Theo C. Pilkington Outstanding Educator Award. For her contribution to education within biomedical engineering, she was elected Fellow in the Biomedical Engineering Society and the American Society of Engineering Education.

Dr. Sophia T Santillan, Duke University

Sophia Santillan joined Duke as an assistant professor of the practice in summer 2017. As a STEM teacher and professor, she is interested in research in student learning and classroom practice. After earning her bachelor's, master's, and doctoral degrees from Duke, Santillan taught at the United States Naval Academy as an assistant professor. She has also worked at the high school level, where she taught across the four-year math curriculum, including advanced courses. She also designed, proposed, and taught two introductory engineering courses for high school students.

Michael Rizk, Duke University
Dr. Jessica Sperling

Dr. Sperling is an applied social scientist and evaluator. She leads the Applied Research, Evaluation, and Engagement area of Duke University's Social Science Research Institute.

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Abstract

This work-in-progress paper describes the implementation and results of surveys to understand the impact of a first-year engineering design course on students. During the Engineering Design and Communication (EGR 101) course, students work in teams to learn and apply the engineering design process to a client-based problem drawn from a community partner. The learning outcomes are to 1) apply the engineering design process to meet the needs of a client; 2) iteratively prototype a solution; 3) work collaboratively on a team; and 4) communicate the critical steps in the design process in written, oral, and visual formats. Students work on one project team for the entire semester, with the focus of delivering a built and tested solution to the client.

To better understand the effects of this course, we used a quantitative evaluation process. The survey addresses how the course contributes to students' self-efficacy and commitment in four areas: professional development, professional skills, engineering/academics, and creativity. Using a repeated-measures design, all students taking the course in fall 2018 were invited to participate in a survey at the beginning and end of the semester (113 paired responses). The survey utilized scale measures assessing intended outcome constructs, with scales adopted and/or adapted from other relevant existing measures. Measurements and analyses included determination of internal reliability for included scale measures (Chronbach's alpha), assessment of statistical significance in observed pre/post change using paired t-test ($P<0.05$), and/or assessment of strength of effect in pre/post change using effect size (Cohen's *d*).

Significant, positive change was seen in general engineering self-efficacy, engineering skills (tinkering) self-efficacy, and engineering design self-efficacy; moreover, engineering design self-efficacy demonstrated notably high strength of effect, as measured by effect size. Within the area of personal development, students showed statistically significant growth in general self-efficacy, but not grit/perseverance. Positive changes in all three of the areas of professional skills, including teamwork, communication, and leadership, were significant and of medium to high effect size. However, these changes across the semester were not seen in engineering academic engagement, which attempted to measure how likely students were to select engineering as a major.

These results provide early evidence of effectiveness for the EGR 101 course in core intended outcomes; results indicate that it is indeed building students' self-efficacy in terms of professional and engineering design skills. Ongoing efforts to further this work are twofold. First, we implemented a parallel data collection process with a second wave of student participants in fall 2019; this will allow us to both build our sample size and determine if the effects are evident across multiple course offerings. Second, current work is underway to evaluate whether these changes persist into students' second year. Particularly, the study will explore whether academic engagement (i.e., declaring a major) is a function of any of these measure parameters. The combination of this current and planned research trajectory will contribute to improve our evidence-based understanding of the contributions of a first-year design-focused course on undergraduates' academic and personal development.

Role of Self-Efficacy in Educational Development

The concept of self-efficacy refers to an individual's judgement of their own capabilities to achieve desired outcomes [1]. According to Social Cognitive Theory [2], self-efficacy is a core factor influencing individual behavior. Perceptions of one’s own efficacy influence “how well people motivate themselves and persevere in the face of difficulties through the goals they set for themselves, their outcome expectations, and causal attributions for their successes and failures” [3]. As a result, individuals with higher self-efficacy are more likely to behave in ways that maximize their likelihood of success.

Within an educational context, academic self-efficacy describes a student’s beliefs about his or her ability to attain educational goals [4]. A systematic review of research examining the relationship between academic self-efficacy and academic performance showed that academic self-efficacy is not only an important predictor of performance among college students, but also influences emotions about learning [5].

The concept of academic self-efficacy may be particularly consequential to efforts aimed at retaining students within a given area of study. Retention of STEM majors is especially important in modern American society, as technology-related careers employ millions of Americans [6]. Nevertheless, despite the importance and appeal of these fields, retention continues to be a challenge in engineering education, disproportionately impacting students of color. According to the American Society for Engineering Education [7], student retention into the second year of engineering programs differs greatly by race, with retention rates for Asian American and White students notably higher than those for African American, Latino, and American Indian/Alaskan Native students. Within engineering specifically, self-efficacy has been shown to be a predictor of persistence within the course of study, even when controlling for other factors [8].

One strategy for establishing self-efficacy involves intentionally creating opportunities for students to experience success in overcoming challenges, or what Bandura refers to as “mastery experiences” [1]. When asked to identify experiences that influence their self-efficacy or confidence in their engineering abilities, undergraduate engineering students often cite such challenges and experiences, mentioning successes in their course work and the design of a functioning device [9] [10] [11]. Similarly, engineering students refer to their understanding and learning of course material, their own motivation, and their course-related abilities as influencing their self-efficacy to perform well in a given course [11].

Project-based first-year engineering courses provide mastery experiences for students and have been shown to positively impact students’ confidence in their tinkering and engineering skills, along with their motivation to continue pursuing their major [10] [12] [13] [14]. Hutchison-Green et al interviewed first-year engineering students to determine what factors, in the students’ first semester, begin to affect self-efficacy [15]. They found that performance comparison (i.e., a student comparing his/her performance to his/her peers) makes a significant impact on self-efficacy, and that depending on the student and the situation, self-efficacy could either increase or decrease in response to the situation. Team-based project courses can thus mitigate the possibility of decreasing students’ confidence because they do not require students to work individually and then compare their performance to that of their peers. Instead, students work together toward a common goal. Team-based projects can improve students' confidence in their collaboration and teamwork skills and even lead students to prefer working on teams [13] [16].

Development of communication skills is another facet of most team-based project courses. Communication skills possessed by engineering students have been assessed over the full curriculum of a given major, as well as within a single engineering design course [17] [18]. Bayles presents an engineering design course requiring students to document meetings, create building instructions, and present testing and evaluation plans for their team project [17]. Surveyed students reported that creating a course structure that relied on clear and effective communication for project success motivated them to more carefully consider their written work.

Description of First-Year Design Course

The Engineering Design and Communication (EGR 101) course at Duke University (Durham, NC, USA) provides first-year engineering students exposure to the engineering design process [19]. All incoming engineering students at Duke are required to take this course, regardless of intended engineering major. The learning outcomes are to 1) apply the engineering design process to meet the needs of a client; 2) iteratively prototype a solution; 3) work collaboratively on a team; and 4) communicate the critical steps in the design process in written, oral, and visual formats. This course was built on best practices in first-year programs as well as engineering education more generally [20].

Students gain and apply technical as well as professional skills while designing a solution to a real-world problem. This one-semester course consists of three components, some of which occur concurrently. In the first component, students develop technical skills (e.g., 3D printing) that are applicable to many of the design projects. In the second component, students learn about the various stages of the engineering design process. In the third component, students apply the engineering design process to solve a problem presented by a client.

In the early portion of the semester, students complete two projects selected from areas such as computer-aided design and 3D printing, circuits and microcontrollers, woodworking, and machine shop (mill and lathe). Students are provided a brief introduction to the technical skills necessary to complete these projects as well as resources to help them as they complete these tools-based projects. The technical skills learned in this early part of the semester form a foundation on which students can build later in the semester.

Throughout the entire semester, the course runs through key stages of the engineering design process such as defining a client's need, performing relevant background research, establishing quantitative design criteria, generating solution ideas, selecting an appropriate solution using a decision matrix, iteratively prototyping and building a solution, and evaluating the solution. Other topics that are crucial for successful completion of a design project are also covered; these include teamwork, project planning, and technical communication. For many of these topics, students perform short in-class activities in which they practice applying the relevant ideas. Each topic is presented at the time in the semester that students begin applying these ideas to their own design projects.

The final component of the course is the design project. Projects are solicited from clients (some from members of the Duke community; others from individuals, non-profits, or companies in the broader community) before the beginning of the semester (examples listed in Table 1). Early in the semester, students rank the projects after reading brief descriptions of the projects and hearing brief pitches from the clients. Based on their project preferences and self-reported technical skills, teams, typically of five members each, are then formed to work on the various projects. As the various stages of the design process are covered in class, teams apply those steps to their own projects. The results of these steps are communicated through a series of technical memos, oral presentations, and ultimately a poster presentation.

Table 1. Sample Projects

Lemur Feeder for Lemur Center
Trash Trap for Ellerbe Creek
Mast Collector for Duke Forest
IV Mannequin for Nursing School
Media Bag Measurement
Sea Lion Enrichment for NC Zoo
Moss Display for Duke Gardens
Solar Panel Cleaner
Post-partum Hemorrhage Simulator
Portable Dental Aspirator

Figure 1. Design POD at Duke University

The physical space for this course and the organization of class time enable students to make a significant amount of progress on their design projects (Figure 1). Each section of the course meets in a design space on the Duke campus equipped with tables at which teams can work collaboratively. The space also has various tools and equipment for prototyping such as 3D printers, laser cutters, power tools, hand tools, electronics stations and components, sewing machines, various fasteners, etc.

The EGR 101 class follows a flipped classroom model [21]. In preparation for class, students watch videos covering relevant content and complete associated quizzes. Class time (roughly 5.5 hours per week) is used for several in-class activities, actively making progress toward solving the design projects, and performing various communication tasks. Teams also spend time working on their projects outside of class. In the second half of the semester, prototyping and testing dominate in- and out-of-class activities. Throughout the course of the design project, teams communicate with and make use of a variety of resources including instructors, teaching assistant, clients, and technical mentors.

Research Methodology

During the academic year 2018-19, we conducted the surveys and analysis discussed in this paper, following our earlier work [19]. Key evaluation research questions primarily addressed the role of the course in student development, with a focus on specific intended outcomes. In particular, we sought to answer: (1) To what degree does the first-year design program affect participants in short-term outcomes such as engineering/academics, creativity, personal development, professional skills? (2) How might these outcomes differ based on student demographic or select educational characteristics?

To address these questions, we developed and utilized a pre-program (Time 1, or T1) and post-program (Time 2, or T2) survey assessment. The target sample included all students participating in the course. T1 data collection was implemented in August 2018, at the semester start. The T2 survey was administered in December 2018, at the close of the semester. All surveys were administered electronically through Qualtrics. In total, 227 students completed the pre-survey, 171 students completed the post-survey, and 113 students completed both (65% and 49% response rate for T1 and T2 assessments, based on program completers). Surveys used a random identifier per respondent (a combination of aspects of a respondent's birth date and phone number). This allowed evaluation researchers to link T1 and T2 data at the individual level but for individual students to remain unidentifiable. All surveys were reviewed and approved by the campus IRB.

Both pre- and post-program surveys addressed outcome measures determined by the program logic model, as articulated by program leadership. These outcome constructs were additionally informed by empirical data collected in Fall 2017 (the first semester of the program), which included qualitative, open-ended data collection from participants on areas of gain [19]. Where available and aligned with intended program outcomes, we utilized validated instruments to address outcome constructs (Table 2). T1 and T2 instruments included multi-item scales for constructs within four core categories: aspects of Engineering/Academics, Creativity, Personal Development, and Professional Skills (Appendix 1).

Table 2. Key outcome constructs with reference for measurement instrument.

Construct	**Measurement Source**
Engineering/Academics	
General engineering self-efficacy	[22]
Engineering skills (tinkering) self-efficacy	[22]
Engineering design self-efficacy	[23]
Engineering academic engagement	n/a, original instrument
Creativity	
Creative self-efficacy	[24]
Value of creativity	[25]
Personal Development	
General self-efficacy	[26]
Grit/perseverance	[27]
Professional Skills	
Teamwork skills	[28]
Communication skills	[28]
Leadership skills	[28]

In the T2 instrument, we additionally utilized a retrospective pre-assessment, implemented at semester end but asking participants to reflect on their knowledge, attitudes, and behaviors at the *beginning* of the semester; this is based on previous research indicating the possibility of illogical decline in outcomes potentially representative of initial overestimation, and it allowed us to consider the relative use of each baseline timepoint in our analysis [29] [30]. In addition, surveys also collected data about intended major at the T1 and T2 timepoints (as measured on a 1-5 scale, based on perceived likelihood of major), race/ethnicity, gender, and course section.

We aggregated individual survey items to create measures for key outcome constructs, with factor analysis used to consider the alpha scores [31] for summary scales. All scales had an alpha at or above 0.7 at both timepoints with the exception of the value of creativity scale at T1, which had an alpha of 0.65. We compared the true- and retrospective-pre timepoints with the post-program timepoint using descriptive statistics and determined to use the true-pre data as baseline (T1). Outcome data was analyzed in SAS using descriptive statistics, paired *t*-tests, and effect size calculations (Cohen's *d*) [32] to determine changes from pre-program to post-program. In addition, for each considered outcome construct, multiple linear regression models were used to additionally account for gender and race/ethnicity.

Results

Results of *t*-test analyses examining outcome constructs strongly indicated student development across nearly all constructs assessed (Table 3). Development of professional skills was clear in all constructs measured. For the significant P values, all changes reflected gains or improvements in measured attribute.

Table 3. P values and Effect Size values are bold if significant ($P<0.05$).

Attribute	**P value**	**Effect Size (Cohen's d)**
Engineering/Academics		
General engineering self-efficacy	**0.00**	**0.32**
Engineering skills (tinkering) self-efficacy	**0.00**	**0.46**
Engineering design self-efficacy	**0.00**	**0.94**
Engineering academic engagement	0.86	-0.02
Creativity		
Creative self-efficacy	**0.00**	0.29
Value of creativity	0.35	-0.09
Personal Development		
General self-efficacy	**0.00**	**0.36**
Grit/perseverance	0.76	0.02
Professional Skills		
Teamwork skills	**0.00**	**0.41**
Communication skills	**0.00**	**0.65**
Leadership skills	**0.00**	**0.35**

Similar results were found using a Cohen's d Effect Size analysis. In particular, we saw significant increases with medium-to-large effect size for teamwork skills, communication skills, and leadership skills. In addition, we saw significant positive change in all measures related to self-efficacy. This included general self-efficacy, general engineering self-efficacy, engineering skills (tinkering) self-efficacy, engineering design self-efficacy, and creative self-efficacy. Moreover, all of these self-efficacy measures, except creative self-efficacy, showed medium-to-large effect size (as measured by Cohen's d).

It is particularly noteworthy, given the focus and intent of the course, that the largest effect size is evident for engineering *design* self-efficacy. While there are open questions about this class as the singular, causal mechanism underlying within-semester changes discussed here, it is sensible to infer that this class was indeed a prime driver in changes in engineering design self-efficacy. In their first semester, very few students participated in other coursework or clubs specific to engineering design. Many of the other foci of the course, including teamwork, communication and leadership, showed increases across the semester. While students may have developed these skills in other venues (e.g., clubs), the consistent increases are notable.

In contrast, we did not observe significant and/or positive change in all constructs assessed. In terms of personal development, while we saw significant positive change in general self-efficacy, we did not see a similar change in grit/perseverance. When considering creativity, while we saw significant positive change in creative self-efficacy, we did not see similar change in valuing of creativity; in fact, this construct slightly decreased. Finally, in terms of engineering-specific measures, we did not see positive change in academic engagement in engineering, the constructed that evaluated the likelihood of continuing engineering classes and declaring a major.

Additional analyses examining the aforementioned outcome constructs and also controlling for baseline and demographic measures show that, in all areas measured, a T1 (baseline) score in outcome construct significantly predicts a T2 score; this is as would be expected. In select areas (general self-efficacy, creative self-efficacy), identifying as male significantly predicts greater T2 improvement when compared to identifying as female. In addition, self-classification as Asian/Pacific Islander is associated with lesser T2 improvements in select areas (general self-efficacy, leadership skills) compared to White-identifying students, though we should note the diversity inherent within this racial/ethnic category and related limitations in interpretability of analyses examining this group.

When holding constant for baseline score, the regression results do not show clear trends across all assessed outcome constructs in terms of the relationship between gender, race/ethnicity, and outcome constructs. In considering these regression analyses, we should note that relatively small sample sizes when subsetting the total number of respondents additionally limit interpretability. Ongoing years of data collection will increase sample size, and these analyses will be revisited as more data becomes available.

Limitations and Future Work

The results of this survey serve as a baseline for evaluating the impact of a first-year design on incoming engineering students. These results show increases in self-efficacy across many dimensions, including general engineering self-efficacy, engineering skills self-efficacy, engineering design self-efficacy, creative self-efficacy, and general self-efficacy. This is consistent with literature taken across many programs [9] [10] [12] [13] [14] [15] [16]. Work is ongoing to analyze student surveys taken from the 2019-2020 academic year. Early analysis would suggest similar trends. The ongoing efforts from the 2019-2020 academic year should approximately double the sample size, which addresses a limitation around sample size in this study. Specifically, we hope to more deeply explore the second research question, which probes how might these outcomes differ based on student demographic or select educational characteristics.

Another limitation of the work is that other activities, clubs, or courses may contribute to the measured increases in self-efficacy, teamwork, communication and leadership. To address this concern, we are conducting surveys for sophomore-level students to evaluate the impact of the course, relative to other issues. In particular, we surveyed sophomore-level students in spring 2019; most of these students didn't take the course (because it was not required), although a few did take the course as an elective [19]. In addition, we will survey sophomore-level students in spring 2020; all of these students will have taken the course.

In summary, this work-in-progress paper presents a survey that measures a range of outcomes to assess the impact of a first-year engineering design course. By surveying the students at the beginning and end of the semester, positive changes in student self-efficacy and students' perceptions of their skills are measured.

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Appendix 1: Survey Instrument

1. Respondent Information

Please provide the following information so that we can link your pre- and post-course survey data.

NetID:
Duke email address:

2. Self-Efficacy, Perseverance, and Creativity

Self-Efficacy, Overall
[7pt Likert-type scale with the following response anchors: 1 = Not at all true, 4 = Somewhat true, 7 = Completely true]

1. I will be able to achieve most of the goals that I have set for myself.
2. When facing difficult tasks, I am certain that I will accomplish them.
3. In general, I think that I can obtain outcomes that are important to me.
4. I believe I can succeed at most any endeavor to which I set my mind.
5. I will be able to successfully overcome many challenges.
6. I am confident that I can perform effectively on many different tasks.
7. Compared to other people, I can do most tasks very well.
8. Even when things are tough, I can perform quite well.

Grit/Perseverance
[7pt Likert-type scale with the following response anchors: 1 = Not at all true, 4 = Somewhat true, 7 = Completely true]

1. New ideas and projects sometimes distract me from previous ones.*
2. Setbacks don't discourage me.
3. I have been obsessed with a certain idea or project for a short time but later lost interest.*
4. I am a hard worker.
5. I often set a goal but later choose to pursue a different one.*
6. I have difficulty maintaining my focus on projects that take more than a few months to complete.*
7. I finish whatever I begin.
8. I am diligent.

Creativity/risk-taking/open-mindedness
Creative self-efficacy

Using the following responses, please indicate the extent to which you agree or disagree that each statement currently describes you. [1 = very strongly disagree, 2 = strongly disagree, 3 = disagree, 4 = neutral, 5 = agree, 6 = strongly agree, 7 = very strongly agree]

1. I feel that I am good at generating novel ideas.
2. I have confidence in my ability to solve problems creatively.
3. I have a knack for further developing the ideas of others.

Valuing of creativity

Using the following responses, please indicate the extent to which you agree or disagree that each statement currently describes you. [1 = very strongly disagree, 2 = strongly disagree, 3 = disagree, 4 = neutral, 5 = agree, 6 = strongly agree, 7 = very strongly agree]

1. If everyone is providing ideas, then no one gets any work done. [r]
2. New ideas seldom work out. [r]
3. Crazy-sounding ideas can lead to something.

3. Teamwork, Communication, & Leadership

Please rate your skill/ability level on each of the following tasks, [6-pt scale, 1 = Unskilled. 2 = Novice, 3 = Intermediate, 4 = Advanced, 5 = Nearly Expert, 6 = Fully Expert]

Teamwork skills
(1) working with others to accomplish group goals;
(2) working in teams of people with a variety of skills and backgrounds;
(3) working in teams where knowledge and ideas from multiple engineering fields must be applied
(4) working in teams that include people from fields outside engineering.

Communication skills
(1) writing a well-organized, coherent report;
(2) making effective audiovisual presentations;
(3) constructing tables or graphs to communicate a solution;
(4) communicating effectively with clients, teammates, and supervisors;
(5) communicating effectively with nontechnical audiences; and
(6) communicating effectively with people from different cultures or countries.

Leadership skills
(1) helping your group or organization work through periods when ideas are too many or too few;
(2) developing a plan to accomplish a group or organization's goals;
(3) taking responsibility for group's or organization's performance; and
(4) motivating people to do the work that needs to be done.

4. Perspective on Engineering and Academics

Self-efficacy in engineering
Please indicate how true each of the following statements is for you [7pt Likert-type scale with the following response anchors: 1 = Not at all true, 4 = Somewhat true, 7 = Completely true]
General Engineering Self-Efficacy (GEN)

1. I can master the content in the engineering-related courses I am taking this semester.
2. I can master the content in even the most challenging engineering course.
3. I can do a good job on almost all my engineering coursework.
4. I can do an excellent job on engineering-related problems and tasks assigned this semester.
5. I can learn the content taught in my engineering-related courses.
6. I can earn a good grade in my engineering-related courses.

Engineering Design Self-Efficacy
Please rate your degree of confidence in performing the following tasks. [5-pt Likert-type scale with 1= not at all confident and 7=completely confident]

1. Researching a design challenge to learn more about the problem and its context
2. Setting design criteria

3. Generating diverse ideas to solve a design problem
4. Selecting a design that meets established design criteria
5. Developing a prototype for a design challenge
6. Testing and evaluating a design to meet established design criteria
7. Using an iterative process while completing a design challenge

Engineering Skills Self-Efficacy (SKILLS)

Please indicate how true each of the following statements is for you [7pt Likert-type scale with the following response anchors: 1 = Not at all true, 4 = Somewhat true, 7 = Completely true]

Tinkering Self-Efficacy

In this section, “tools” is broadly defined to include both mechanical and computational tools (e.g., 3D printers, shop tools, software/programming tools).

1. I am comfortable learning new tools.
2. I can work with tools and use them to build things.
3. I can work with tools and use them to fix things.
4. I can work with machines.
5. I can build machines.
6. I can fix machines.
7. I can manipulate components and devices.
8. I can assemble things.
9. I can disassemble things.
10. I can apply technical concepts in engineering.

Engineering Academic Engagement

Please indicate how true each of the following statements is for you [7pt Likert-type scale with the following response anchors: 1 = Not at all true, 4 = Somewhat true, 7 = Completely true]

1. I think engineering is fun.
2. I am extremely interested in engineering.
3. I am definitely going to pursue a career in engineering.
4. Engineering is the right career for someone like me.

5. Please rate how likely you are to major in each of the following subject areas: (5-pt Likert scale with 1=not at all likely, 2 = somewhat likely, 3= likely, 4=very likely, 5 = extremely likely)
   a. Biomedical Engineering
   b. Civil Engineering
   c. Electrical & Computer Engineering
   d. Environmental Engineering
   e. Mechanical Engineering
   f. Trinity- non-STEM Major
   g. Trinity – STEM Major

6. [Post-program only] How, if at all, has your experience in the Engineering 101L course affected your academic plans (e.g., intended major)? Please describe below.

5. Background/Personal Information (*pre-program survey only)

Please indicate which section of the EGR101L course you were enrolled in this semester. [drop-down menu with course section numbers listed, e.g., 001-006]

Race/ethnicity (select any/all that describes your identity):
Asian/Pacific Islander
Black/African American
Hispanic/Latino
White/Caucasian
Other

Gender (select the option that best applied to you, based on your self-identity):
Male
Female