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Tracking Skills Development and Self-efficacy in a New First-year Engineering Design Course

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Abstract

This evidence-based practice paper describes the development and implementation of surveys and a focus group to understand the impact of a new first-year engineering design course. With the intent of adding a practical design experience for first-year students, the Engineering Design and Communication course was introduced as a pilot program in the fall of 2017 at Duke University. Over the course of a semester, students work in teams to learn and apply the engineering design process to a client-based problem drawn from a community partner. In the course, the students should learn to 1) apply the engineering design process to meet the needs of a client; 2) iteratively prototype a solution using appropriate tools and materials; 3) work collaboratively on a team; and 4) communicate the critical steps in the design process in written, oral, and visual formats. The course was created following many best practices in first-year engineering education.

This paper focuses specifically on how the course contributes to students' confidence about themselves as engineers, students' understanding of the engineering design process, and students' progress in technical skills. The paper also assesses students' satisfaction with the course. This information is designed to help leaders in the engineering school comprehend the specific impact of the first-year design course, in addition to laying the foundation for a long-term retention study.

There are two parts of this study: online surveys and a focus group. The participants for the surveys included subsets of the 48 freshmen students in the course. To conduct this data collection, three surveys were administered to generate paired data used to investigate trends over time. To generate qualitative data and gain insight into what might be underlying the results of the surveys, a focus group session was conducted.

Statistical analyses, including two-sample t-tests, paired t-tests, and chi-squared tests, were conducted with the survey data to determine significance of changes over time. Qualitative data from the open-ended questions was evaluated by frequency of response. Major findings from this study include: students definitively progressed in crafting, CAD, and rapid prototyping over the course of the semester; participants' confidence in each step of the engineering design process increased; and the course was successful in providing students with real-world experiences that positively contributed to their engineering self-efficacy.

Self-efficacy in Engineering

Nationwide, university administrators, faculty members, industries, and organizations are striving to increase retention within engineering. When considering first-to-second-year retention rates for engineering degrees, the American Society for Engineering Education investigated trends from 2003 to 2012 and found an overall increase in retention rates, but rates remained below 80% on average [1]. Previous literature has investigated the role of a student's self confidence in engineering in terms of year-to-year retention at the university level. Researchers have discovered that only a minor portion of engineering students (as low as 8.5%) leave due to academic difficulty

[2, 3, 4]. By restructuring programs to focus on first-year retention, many institutions observed positive retention results [5, 6]. After introducing a first-year engineering projects course at the University of Colorado at Boulder, Knight et al. found that students who took the course demonstrated increased retention when compared with their peers who did not take the course [3]. When Knight et al. discussed possible explanations for this increased retention, they attributed it to “the impact of active hands-on pedagogy, creation of student learning communities, an early experience on the human side of engineering, self-directed acquisition of knowledge by students, instructor mentoring, and the success orientation of the course” [3]. It has been shown that if students have a strong, positive conviction about their knowledge in engineering, then they are more likely to succeed academically in the specific subject, as well as in engineering-related subjects [7]. Aleta also stated that the engineering design experience was found to be the main indicator of academic achievements in both math and related engineering subjects [7].

Self-efficacy is defined as one’s belief in one’s ability to achieve a specific task or succeed in a particular area by achieving the intended results [8]. For students, this may dictate their academic execution from a cognitive aspect, as their personal efficacy can positively influence their outlook on performance and potential to succeed. Bandura illustrates the importance of academic self-efficacy by asserting that “students’ beliefs in their efficacy to regulate their own learning and to master academic activities determine their aspirations, level of motivation, and academic accomplishments” [8]. In the context of engineering, this is essential as students navigate technically challenging coursework and rigorous workloads. Self-efficacy has a strong relationship to both learning and achievements. As Mamaril et al. state, it is most effective to measure self-efficacy at both the general engineering field level and the specific technical skill level [9]. Evaluating at these different levels yields a more comprehensive understanding of a student’s confidence in their overall engineering abilities.

A major contributor to a student’s self confidence in completing engineering tasks is their perceived proficiency in technical skills. Usher et al. investigated students in undergraduate engineering and determined that experiences that specifically enact a student’s increased sense of capabilities were vital to their self-efficacy [10]. In another study, the author examined a senior engineering project that utilized the design process and discovered a positive trend of increased self-efficacy over time [11]. The resulting conclusions noted that there is a time-dependency, thus possibly an experience-dependence for these advances. This is potentially indicative of self-efficacy gains specifically from successful experiences. The study also denotes self-efficacy and teamwork skills as critical elements of a successful engineering career [11].

Literature has highlighted the importance of not only teaching technical skills, but allowing students to apply them in a hands-on manner in the framework of an engineering project to constructively impact their personal efficacy. Morocz et al. presented evidence revealing a relationship between students’ levels of participation in makerspaces during their first year and their confidence in completing engineering design tasks [6]. The real-time application of learned skills provided students with an outlet to see their coursework come to fruition, producing a positive impact on their engineering self-efficacy.

First-Year Design Courses

Multiple institutions have implemented novel first-year design courses to engage students in hands-on experiences. While some focus on a series of short projects, some on design and exposure to a programming language such as MATLAB, and a few on full-semester, client-based design projects, all seek to increase retention and improve understanding of engineering concepts at an early stage. Below, a few of many quality program are described; these were selected because they highlight and assess topics of interest to our program, including creativity, real-world design challenges, and development of technical skills and self-confidence.

With the intention of exhibiting that engineering is a creative process and increasing interest in electrical and computer engineering (ECE), The University of Alabama developed a design laboratory freshmen course for ECE students [12]. In this course, the creative process for the students' designs included brainstorming, planning, and implementing design solutions. The authors found that students who participated in the creative lab demonstrated a higher confidence in continuing in engineering coursework than those who did not. As the study states, "Creativity is an important attribute for engineers practicing their profession in a global society" [12]. Although students struggled with the open-ended nature of the design problems, they enjoyed the course and saw the value in the addition to their curriculum.

Illustrating the importance of incorporating real-world engineering design problems, Odeh et al. write, "Nowadays, engineering education needs to meet the requirements and needs of business and industry. This can be achieved by collaborating with the local industry to adopt real life engineering design problems" [13]. In this study, a first-year innovative engineering design course is offered to students of various engineering disciplines and includes design problems that facilitate application of basic engineering concepts to real-world problems [13]. They found that student satisfaction with the course was high (88%) and that placing them in projects based on their discipline improved their perception of engineering while granting them the opportunity to work in teams similar to those experienced in industry. Students were also more confident in choosing their final major as they were able to acquire a better understanding of each engineering major.

At Massachusetts Institute of Technology, the Department of Aeronautics and Astronautics offered a first-year design course centered around real-world engineering experience through a hands-on vehicle design project [14]. The students found the experience empowering, and surveys showed they were much more comfortable tackling technical problems without clear answers. The students' comfort with technical skills and attitude towards teamwork also improved over the course of the semester.

The outcomes of these studies are vital when exploring the concept of engineering self-efficacy. Carberry et al. state, "Opportunities for mastery experiences, vicarious experiences, social persuasion, or positive and negative physiological states with engineering design may not naturally occur unless the individual has had some sort of experience." which is why "…engineering design self-efficacy is highly dependent on engineering experiences" [15]. With the results of similar first-year, design-based engineering courses, the objectives of this one-semester course align with findings in literature. These project-based design courses have been shown to contribute to development in confidence in technical skills, increased commitment to engineering, and improved self-efficacy.

In this paper, we are evaluating many of the ideas of self-efficacy, skills development, and commitment toward engineering in a course with full-semester, client-based design projects from a wide range of fields. As first-year programs consider moving toward more authentic projects, this study can provide guidance as to the impact of such a course.

Engineering Design Process and Course Description

This new one-semester course offered to freshmen provides an early opportunity to use engineering skills to solve real-world problems. Prior to this, students would not have this hands-on project-based experience until their senior year unless they are specifically enrolled in one of a few courses. At Duke University, the first-year program has previously only consisted of introductory STEM courses including math, physics, chemistry, a beginning writing course, and a programming course that teaches MATLAB. The programming course is the only engineering-specific course required and gives a narrow scope of the field. With the new, first-year design course comes the opportunity for students to experience the practical engineering process, comprehend how knowledge from fundamental courses can be applied, and work with an external client. All of these activities are geared towards encouraging retention in engineering by providing early exposure to realistic projects.

The objective of introducing this new course, Engineering Design and Communication, is to provide a space where students in various departments can come together to work on engineering design activities, as they would work on interdisciplinary teams in the real world. By the end of the course, students are expected to 1) successfully solve their client-based design challenge by following the critical steps in the engineering design process, 2) develop proficiency to safely use one or more prototyping strategies/tools, 3) work collaboratively on an engineering team, 4) write technical memos, present oral reports with supporting visuals, and present a poster that captures critical steps, 5) and use a Gantt chart to manage the project. The classroom is equipped with tools for the students to use so they can learn various technical skills and apply them to their solution for their client's problem. In exposing them to real-world engineering early in their undergraduate career, the hope is that the course will help students determine if they are passionate about engineering. Enrollment of the class was limited to 48 students, intended to accurately represent the engineering school's wider demographics.

In the class, students learn the engineering design process in several steps and use it to solve problems drawn from community partners (Table 1). Each design team is assigned an upperclassman teaching assistant to aid them throughout the process. In this course specifically, the engineering design process is defined as seen in Figure 1.

Table 1. Student Projects in Fall 2017.

Design Project	Goal
Acetic Acid Application	Incorporate a method to apply acetic acid onto the cervix while using a pocket colposcope
Bear Feeder	Automatically feed the black bears at unpredictable locations and times
Brainwave Headset Test Jig	Design a test jig for the headset to verify that individual devices are detecting realistic human brain EEG signals
Flexible Lemur Feeders	Build a flexible feeding system for lemurs that can be placed 15-20 feet up a tree
Improved Eating Utensils for Kelsie	Develop a spoon and fork for a young woman who has cerebral palsy
Drone Water Sampler	Build a drone attachment that collects a single water sample
Oxygen Cylinder Storage on Walkers	Build a new storage system for three oxygen cylinders for use with rollator walkers
Cold Frames at XXXXX Gardens	Develop an automated system to raise and lower lids on cold frames based on temperature
Simulation Device for IV Injection Training	Design a more realistic simulation device for training students in IV injection.
Trash Collection from Local Creek	Remove floating trash from local creek.

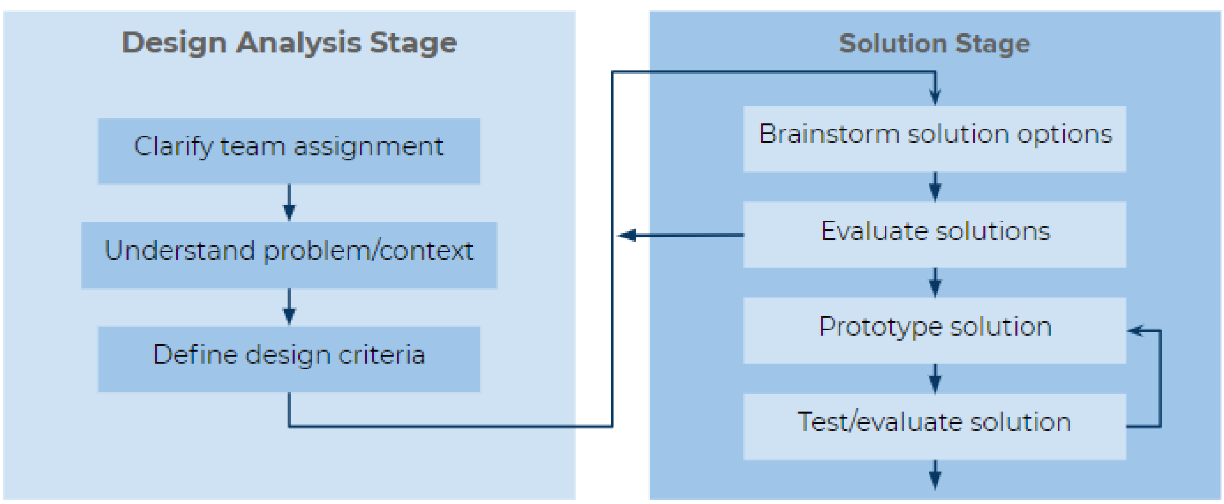

Figure 1. Engineering design process as defined in the course.

While the engineering design process is not an identical list of tasks across all practices, the concept is universal. During the design process, students use a structured approach and a series of steps to create a product that meets established design criteria. As Guerra et al. state, "The engineering design process provides the appropriate discipline, from understanding the proposed challenge to determining the best solution. The intent of introducing the process to a pre-engineer audience is to ensure thinking before tinkering" [16]. Understanding and applying the design process to projects in this and future courses is important [16]. Assessing students' self confidence in these specific steps over the duration of the semester yields an accurate account of their beliefs in themselves in successfully executing the engineering design process [17].

In the context of the Engineering Design and Communication course, technical skills lessons are formulated and opportunities for application follow with the client-based design challenge. These technical skills are divided into five main categories: electronics, crafting, programming, CAD, and rapid prototyping. As student groups work on different projects for community partners, these skills are used in varying capacities throughout the semester. The students work in a new makerspace that includes equipment used in those previously mentioned technical skills modules and also needed for construction of their prototypes.

Materials and Methods

All work was conducted in compliance with Internal Review Board (IRB) policies set forth by Duke University. There were two parts of the study: three online surveys and one focus group. To collect data, the surveys were administered at the beginning, middle, and end of the semester to generate paired data used to investigate trends over time (Figure 2). Each survey took less than 20 minutes to complete and gathered demographic information including age, gender identification, race/ethnicity, and intended major(s)/minor(s). Survey 1 and Survey 3 consisted of four parts: self-ranking of technical skills competency (beginner, intermediate, advanced, or expert), self-ranking of confidence in essential parts of the engineering design process using a five-point Likert scale (Figure 3), degree of agreement with statements related to general engineering self-efficacy using a five-point Likert scale (Figure 4), and open-ended questions related to those topics. The second survey included all of those previously stated elements, with the exception of the open-ended questions and demographic information. The survey questions were adapted from existing, published surveys [11, 16, 17], and the specific questions asked can be found in Appendix A.

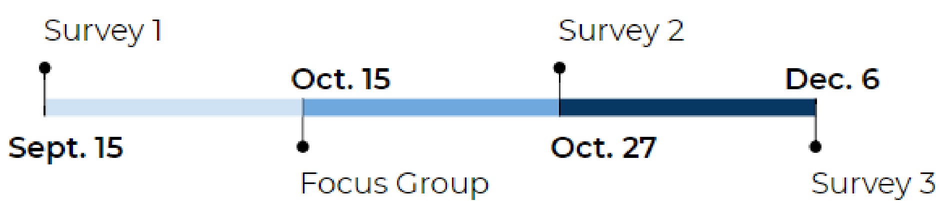

Figure 2. Study timeline.

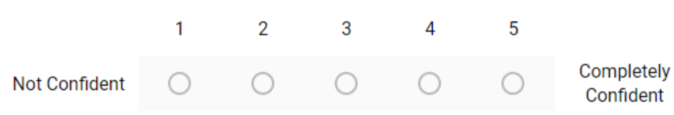

Figure 3. Five-point Likert scale for engineering design process steps.

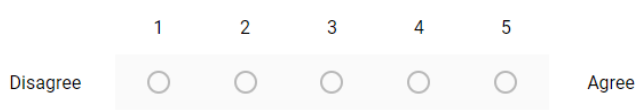

Figure 4. Five-point Likert scale for engineering self-efficacy statements.

While all 48 students were invited to participate, not every student responded to every survey. For the first survey, 31 out of the 48 enrolled students participated. Between the first and second surveys, there were 22 common respondents; between the first and third surveys there were 26 common respondents, and there was a total of 20 participants who participated in all three surveys. It is understood that the size of the sample is small, and the results would need to be replicated. The race and gender demographics of the sample population were representative of the full course enrollment (Appendix C).

Progression of technical skills was explored between the first and third survey. Chi-square tests were conducted to ascertain if the distribution of responses for technical skills proficiency shifted over the semester. For survey questions utilizing Likert scales, paired t-tests were conducted to determine if there were statistically significant changes in an individual's response over the three surveys. To analyze the open-ended questions of Surveys 1 and 3, the recorded answers were examined and the responses with the highest frequencies were noted (Appendix B).

To investigate potential differences between demographic groups, both gender and racial identification were examined. Gender groups included male and female, as no participant identified as anything other than those two categories. Racial identification was broken down into majority (White and Asian) and underrepresented minority (Black or African American, Hispanic or Latino or Spanish origin of any race, and two or more races). Two-sample t-tests were used to distinguish statistically significant differences. Demographic information can be found in Appendix C. All statistical analyses were conducted with a significance level of 0.05.

To generate more qualitative data, a focus group study was conducted between Survey 1 and Survey 2. Two focus groups were assembled, one with six students and one with four students; each session lasted approximately 45 minutes. The same questions were posed to both groups; the focus group questions were designed to explore the results from the first survey in more detail. The questions were centered on students' experiences thus far as first-year engineering students at Duke University, their impressions of the design course itself, and students' engineering self-efficacy. Students were advised that their answers were anonymous, and the audio recording that was implemented for note-taking purposes was deleted after the analysis was completed. The specific focus group questions can be found in Appendix D.

Results

Technical Skills Progression

Students were asked to rank themselves in terms of proficiency by indicating "beginner, intermediate, advanced, or expert" for each technical skills category. Survey 1 and Survey 3 were compared to identify a shift over the course of the semester (Figure 5). Using a chi-square test, there was a statistically significant shift ($p<0.02$) in the distribution of responses from Survey 1 to Survey 3 for rapid prototyping. To further assess the results, the "intermediate", "advanced", and "expert" categories were grouped into a new category titled "non-beginner." Then, differences between beginner and non-beginner status for each of the five skills were investigated. The results are listed in Table 2, and there were statistically significant shifts from beginner to non-beginner levels for: crafting ($p<0.001$), CAD ($p<0.01$), and rapid prototyping ($p<0.001$).

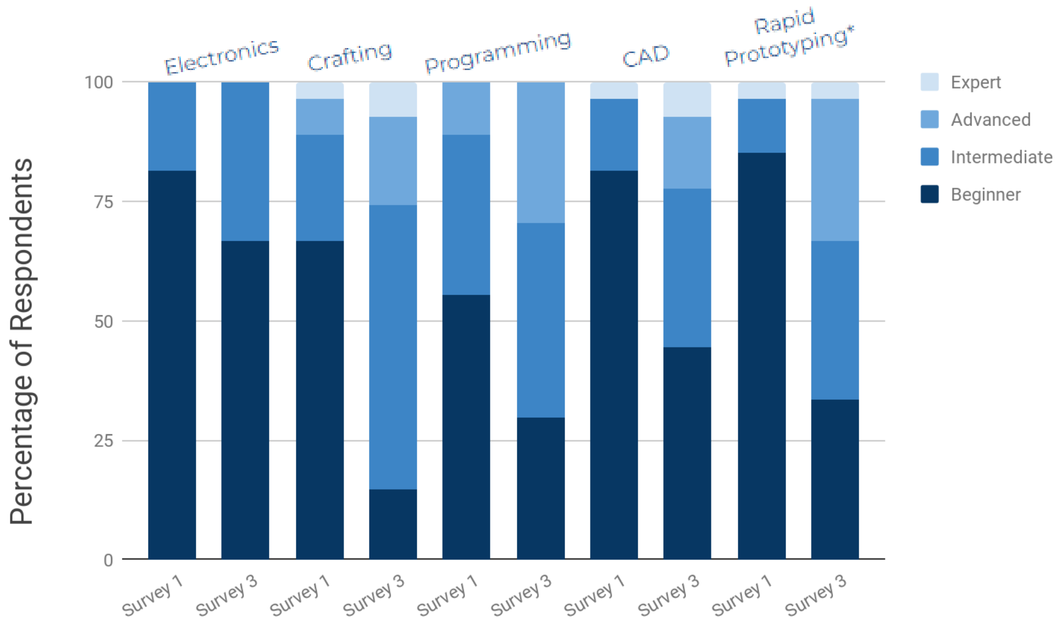

Figure 5. Clustered columns displaying technical skills progression between Survey 1 and Survey 3 (*p<0.02).

Table 2. Increase in percent of non-beginners (intermediate, advanced, and expert) from Survey 1 to Survey 3.

Technical Skill Category	**Survey 1 (% of non-beginners)**	**Survey 3 (% of non-beginners)**	**% Change**	**P Value**
Electronics	18.5	33.3	14.8	>0.05
Crafting	33.3	85.2	51.9	<0.001
Programming	44.4	70.4	25.9	>0.05
CAD	18.5	55.6	37.0	<0.01
Rapid Prototyping	14.8	66.7	51.9	<0.001

Engineering Design Process

The engineering design process as previously outlined in Figure 1 was broken down into 11 statements that students ranked on a five-point Likert scale. Table 3 outlines the results that yield statistically significant increases at every step of the design process from Survey 1 to Survey 3. There was a larger change from Survey 1 to Survey 2 than from Survey 2 to Survey 3. The three highest changes were seen in developing a prototype for a design challenge (Q8), setting design criteria (Q5), and using an iterative process to complete the design challenge (Q10).

Table 3. Engineering design process results.

Q	Step	Survey 1 Average	Survey 2 Average	Survey 3 Average	Difference btw 1 & 3	P value
1	Identifying a design problem from the community	3.40	4.30	4.20	0.80	<0.005
2	Incorporating client feedback to improve a design solution	3.80	4.35	4.60	0.80	<0.005
3	Clarifying scope and important features of a design project through client interactions	3.60	4.30	4.55	0.95	<0.005
4	Researching a design challenge to learn more about the problem and its context	3.40	4.00	4.40	1.00	<0.005
5	Setting design criteria	2.85	4.10	4.35	1.50	<0.005
6	Generating diverse ideas to solve a design problem	3.40	4.05	4.25	0.85	<0.005
7	Selecting a design that meets established design criteria	3.45	4.15	4.35	0.90	<0.005
8	Developing a prototype for a design challenge	2.55	4.00	4.35	1.80	<0.005
9	Testing and evaluating a design to meet established design criteria	2.95	3.65	4.05	1.10	<0.005
10	Using an iterative process while completing a design challenge	3.05	4.20	4.55	1.50	<0.005
11	Working with a client to complete a design project	3.75	4.10	4.45	0.70	<0.005

Engineering Self-Efficacy

Statements of engineering self-efficacy were divided into three categories: A) academic self-efficacy; B) intention to pursue engineering; and C) general statements about engineering self-efficacy (Table 4). For the first three statements concerning academic self-efficacy (category A), a slight increase was observed for confidence in performing well on engineering problems in this course and at Duke University. A slight decrease in self-confidence in other STEM courses was seen. None of these changes were statistically significant. In category B, both intention to pursue an engineering degree and an engineering career decreased 0.1 points over the course of the semester. This decline was also not statistically significant. In category C, which related to general statements of engineering self-efficacy, five of six statements increased in a significant manner ($p<0.02$). The statement “design skills are important for engineers” was unchanged.

Table 4. Engineering self-efficacy results.

	Statement	Survey 1 Average	Survey 2 Average	Survey 3 Average	Difference btw 1 & 3	P value
A	I can perform well on engineering design problems in this course	3.80	4.35	4.36	0.56	<0.05
	I can perform well in other STEM courses (e.g. Biology, Math, Programming, Physics, etc.)	4.45	4.15	4.25	-0.20	>0.05
	I can perform well academically at Duke University	4.10	3.95	4.21	0.11	>0.05
B	I intend to pursue an engineering degree	4.70	4.65	4.60	-0.10	>0.05
	I intend to pursue an engineering career	4.40	4.40	4.30	-0.10	>0.05
C	I can successfully apply the engineering design process to meet the needs of a client	3.80	4.45	4.55	0.75	<0.001
	I can successfully communicate a final design to a client	3.85	4.40	4.55	0.70	<0.001
	I can work collaboratively on a team to design an engineering solution	4.00	4.50	4.70	0.70	<0.001
	I can apply technical skills to engineering design problems	3.75	4.25	4.40	0.65	<0.02
	Design skills are important for engineers	5.00	4.95	4.95	-0.05	>0.05

Demographic Differences

When exploring any possible differences between gender and race, responses from all surveys were used for comparison. For all three sections of the survey (technical skills, understanding of the engineering design process, and engineering self-efficacy), there were no significant differences between the responses of male and female students for all three surveys. It should be noted that the average female confidence in the steps of the engineering design process was lower than that of males on all three surveys, but no averages were significantly lower.

Differences between the majority and underrepresented minority students were also examined. For all three sections of the survey, there were no statistically significant differences between the two groups, except for the statement "I can successfully communicate a final design to a client." For that specific statement, underrepresented minority students ranked themselves > 0.5 points higher in agreement than the majority students did on all three surveys.

Open-Ended Questions

For the open-ended questions on the first survey, the responses were analyzed and common themes throughout the answers were identified. Frequencies of responses are recorded in Appendix B. When asked to pinpoint the most important things that they expected to learn in the class, students responded with specific ways that the course can help them, including how to: work with and collaborate with a team, use the engineering design process, communicate effectively with classmates and clients, as well as apply technical skills. In terms of growing as an engineering student, participants listed exposure to 'real world' engineering, using the engineering design process, increasing their creativity and innovation, and collaborating with a team. When asked for the most challenging aspect of STEM coursework they had experienced thus far, most student listed math, with the transition from memorization to critical thinking/theory-based learning, self-teaching concepts to supplement lectures, and time management as the main obstacles. It is important to note that students were taking various math courses. When asked which part of the Engineering Design and Communication course they were most concerned about performing well in, students noted the actual prototyping and building of the product, correctly applying learned technical skills to their design solution, creating a successful and effective product for their client, and working well in teams. For skills that they would like to develop most in this course, technical skills, communication skills, teamwork, and creativity were the most frequently listed.

The open-ended questions for Survey 3 were also evaluated and frequencies for each response are recorded in Appendix B. As the semester came to a close, participants were asked to reflect on their most difficult STEM course; math was a resounding answer with 78% of participants including that course in their response. When asked why their most difficult courses were so challenging, students replied that understanding key concepts, sizeable workloads, and fast-paced classes made courses tougher to navigate. While the dormitory was listed as the greatest sense of community for respondents, 93% of students stated that this course contributed to their sense of community, as small groups and like-minded classmates aided in their transition from high school to college. The definition of self-efficacy was given to students, and they were subsequently asked if this course contributed to their sense of engineering self-efficacy. One hundred percent of students said that the course contributed positively to their self-efficacy as it increased their confidence in their engineering abilities, they gained key technical skills that they can apply to future coursework, and it provided the real-world engineering experience that they hoped to gain. Students were asked to list the three most important things they learned this semester in the course. The responses were the same as Survey 1 in the same order, namely collaborating with a team, learning the engineering design process, communication with both clients and teammates, and technical skills.

Focus Group

For the focus group study, the two sessions yielded slightly different responses, but many of the themes remained consistent between groups. The first finding was that students stated the

School of Engineering was difficult and stressful at times, but the degree was undoubtedly worth it. Students did mention an underlying pressure to succeed because the School has such a prestigious reputation. For that reason, participants claimed that they were more worried about completing their engineering degree at Duke University than they were about being successful in the engineering industry after graduation. As was reflected in the open-ended responses from Survey 1 and Survey 3, participants in the focus group also listed math as their most difficult STEM course. As far as their opinions on the Engineering Design and Communication course, students had a positive experience to date in the class. They appreciated learning a quantitative approach to choosing a design solution as well as the unique opportunities the course provided which they might not find elsewhere at Duke. Students elaborated on learning the engineering design process, saying the process is different than expected as it took much more time than they thought would be necessary for choosing a solution, but they appreciated its application as well as the ability to utilize the process on problems in the future. For students who felt incoming first-year students had variable experience in different technical areas, they thought this course served as a "leveling" opportunity, meaning no matter the amount of experience, they did not feel disadvantaged within the assignments or projects. Participants also noted that working with a client on a project was a key factor of the course impact, as well as their motivation to successfully complete their project on time.

Discussion

Technical Skills

For the progression of technical skills, Table 2 provides the most helpful results in demonstrating the transition from beginner to non-beginner. As previous literature states, students' confidence in their ability to be proficient in technical skills is key to their engineering self-efficacy [11, 18]. Students viewing themselves as non-beginners is a positive step in that direction, indicating an increased self-assurance in utilizing those skills in this course, as well as courses to come. For example, more than 85% of respondents considered themselves non-beginners in crafting (e.g. woodworking, model building, prototyping, etc.) by the end of the semester and this result speaks to the course's influence on their newly found confidence in that area. Rapid prototyping tools (e.g. 3D printing, laser cutting, etc.) were also used by many teams to complete their prototypes and related coursework. In the area of rapid prototyping, there was a 51% increase in non-beginners, and we suspect that this also impacted students' engineering self-efficacy. This course allowed students to learn and directly apply technical skills in real-time as they completed their projects. As indicated in their open-ended responses, this experience likely contributed to the participants' confidence in their abilities.

Engineering Design Process

A major element of this course was learning and applying the engineering design process. The increase in confidence for each step in the process is a positive result of the class. Applying the engineering design process was deemed a useful outcome of the course by students in both open-ended survey questions and the focus group. The ability to apply the design process to future coursework is also a benefit of the class.

The largest point increase from Survey 1 to Survey 3 was for the step regarding prototyping (Question 8), which increased from 2.55 to 4.35 (~70% increase). This step went from the lowest confidence for students to being one of the top ranked steps. This result speaks to the focus of prototyping in the course; most teams used several tools (e.g. 3D printing, crafting, Arduino, etc.) in developing iterative prototypes. It makes sense that prototyping and using an iterative process to complete the design challenge increased the most as the course placed a strong emphasis on those steps. Students had most likely never had to set design criteria before, rendering it feasible to be among the largest increase in confidence over the course of the semester. Overall, students' perceptions of their skills in engineering design improved over all steps of the design process.

Engineering Self-Efficacy

While there was a slight increase in students' confidence in performing well at the university level, it remained the lowest rated statement in the engineering self-efficacy section. The minor decrease in students' belief in performing well in other STEM courses also speaks to the academic self-efficacy of engineering students that participated in these surveys. While their confidence in this course increased, the same optimism did not transfer to other STEM courses. This is an important finding because in qualitative data, students consistently claimed they felt that lessons learned in this course could be applied to future coursework, yet their confidence for forthcoming classes did not increase as a result.

For the intention of pursuing both an engineering degree and career, both statements decreased by 0.1 points over the course of the semester. This decrease was not statistically significant. While students' intent to pursue engineering did not increase, that intent also did not lessen. When compared with national retention rates of 75-80% from first to second year, this can be seen as a positive outcome [1]. While it is known that engineering self-efficacy is not the only factor in engineering degree retention, it is an important component.

The remaining statements illustrate other aspects of engineering-efficacy; all statements demonstrated significant increases over the semester except for the importance of design skills for engineers. From these results, it can be concluded that students feel confident in applying the engineering design process to meet actual design needs, and can subsequently communicate that solution to clients. The one-to-one ratio of what students expected to learn as compared to what they actually learned likely contributed to their satisfaction with the course and consequent confidence in those areas.

The absence of differences between racial groups is consistent with existing literature. Marra et al., as well as Concannon and Barrow, found that the subject's ethnicity did not significantly correlate with the resultant means of self-efficacy survey question responses over time [19, 20]. For differences between gender groups, there were none observed in this study, as is the case in other literature. Concannon and Barrow determined that there were statistically significant differences between male and female gender groups for coping self-efficacy but not for engineering self-efficacy, which they also stated was consistent with other literature [19].

Limitations and Future Work

Some limitations of this study include the limited sample size with only 20 common respondents between all three surveys. In future studies, it would be beneficial to compare results from students in the Engineering Design and Communication course with first-year students not enrolled in the course. This would yield useful conclusions about the isolated impact of this new course on students' engineering self-efficacy, as other courses may have influenced responses.

It may also be valuable to investigate the contribution of communication skills to students' sense of confidence in engineering. Communication skills were an integral part of this first-year course and something students expressed as being unique to the class. It would be noteworthy to see if their confidence in communication skills increased over the course of the semester and if that change would have contributed in any way to their engineering self-efficacy as they strive to become well-rounded engineers. Another intriguing finding was that the largest increase in most statements occurred between Survey 1 and Survey 2. Future research can be done to see if this is consistent among other courses and if there is any reasoning behind a larger increase in the first half of the semester when compared with the second half.

Conclusion

The objective of this study was to assess students' confidence in engineering as this is a critical factor in engineering retention. Participants were asked at the beginning, middle, and end of the semester to self-rank their proficiency in technical skills, understanding of the engineering design process, and confidence in other areas of engineering. Through statistical analyses, it can be concluded that students became increasingly confident in crafting, CAD, and rapid prototyping over the course of the semester as they shifted from self-proclaimed beginners to non-beginners. Statistically significant improvements in self-confidence were observed for every step in the engineering design process. Several other statements related to engineering self-efficacy also increased during the semester. These elements combined with stagnant responses for intention to pursue engineering demonstrate positive indicators for engineering retention for this cohort. Through open-ended responses and two focus group sessions, students stated the Engineering Design and Communication course positively contributed to their engineering self-efficacy and provided experiences that sustained optimism for pursuing engineering. Coupling engineering lessons with hands-on design problems resulted in a positive experience for students.

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Appendix A - Survey Questions

<u>Participant Information</u>

Unique ID:
Age:
Gender Identification:
Race/Ethnicity:
School:
Pratt Intended Major:
Intended Minor (if any):
Trinity Intended Major:
Intended Minor (if any):

<u>Technical Skills</u>
Please list the amount of direct time you have spent learning and/or applying the following skills:
(Note - only include time you physically spent learning/applying skill, not elapsed time):

	No time	1-8 hours (ex: several class periods of introductory work)	1 - 3 days (ex: used in a multi-day crash course)	3 days - 2 weeks (ex: used over several weeks in a course)	2 - 8 weeks (ex: used consistently in a summer internship)	> 8 weeks (ex: used for entire semester of coursework)
Electronics (building circuits, Arduino, etc.)	☐	☐	☐	☐	☐	☐
Crafting (woodworking, model building, prototyping, etc.)	☐	☐	☐	☐	☐	☐
Programming (C/C++, Java, Basic, MATLAB, etc.)	☐	☐	☐	☐	☐	☐
CAD (SolidWorks, Tinker CAD, etc.)	☐	☐	☐	☐	☐	☐
Rapid Prototyping (3D printing, laser cutting, CNC, etc.)	☐	☐	☐	☐	☐	☐

Please rank your proficiency in the following skills:

	Beginner	Intermediate	Advanced	Expert
Electronics (building circuits, Arduino, etc.)	☐	☐	☐	☐
Crafting (woodworking, model building, prototyping, etc.)	☐	☐	☐	☐
Programming (C/C++, Java, Basic, MATLAB, etc.)	☐	☐	☐	☐
CAD (SolidWorks, Tinker CAD, etc.)	☐	☐	☐	☐
Rapid Prototyping (3D printing, laser cutting, CNC, etc.)	☐	☐	☐	☐

<u>Self-Efficacy</u>

Rate your degree of confidence in performing the following tasks:

	1	2	3	4	5	
Not Confident	○	○	○	○	○	Completely Confident

- Identifying a design problem from the community
- Incorporating client feedback to improve a design solution
- Clarifying scope and important features of a design project through client interactions
- Researching a design challenge to learn more about the problem and its context
- Setting design criteria
- Generating diverse ideas to solve a design problem
- Selecting a design that meets established design criteria
- Developing a prototype for a design challenge
- Testing and evaluating a design to meet established design criteria
- Using an iterative process while completing a design challenge
- Working with a client to complete a design project

Rank your agreement with the following statements:

	1	2	3	4	5	
Disagree	○	○	○	○	○	Agree

- I can perform well on engineering design problems in this course
- I can perform well in other STEM courses (e.g. Biology, Math, Programming, Physics, etc.)
- I can perform well academically at Duke University
- I can apply technical skills to engineering design problems

- Design skills are important for engineers
- I intend to pursue an engineering degree
- I intend to pursue an engineering career
- I can successfully apply the engineering design process to meet the needs of a client
- I can successfully communicate a final design to a client
- I can successfully apply the engineering design process to other problems
- I can work collaboratively on a team to design an engineering solution

Open-Ended Questions – Survey 1

Please use at least 2-3 sentences to answer each question. Please use as much detail as necessary to fully address the question.

- What do you consider the three most important things you will learn in this class and why?
- How do you think this course will help you grow as an engineering student?
- What has been the most challenging aspect of STEM coursework thus far and why?
- What part of this course are you most concerned about performing well in and why?
- What skills would you like to develop most in this course and why?

Open-Ended Questions – Survey 3

Please use at least 2-3 sentences to answer each question. Please use as much detail as necessary to fully address the question.

- What is currently the most difficult STEM course you are taking and why? Is it difficult because of concepts, workload, etc.?
- Where have you found your greatest sense of community at Duke so far?
- Has the Engineering Design and Communication class contributed to your sense of community? Why or why not?
- Self-efficacy is defined as one’s belief in one's ability to achieve a specific task or succeed in a particular area by achieving the intended results. In the context of this course, has it contributed to your engineering self-efficacy positively, negatively, or not at all? Why?
- Are there any other courses/experiences that are contributing to your engineering self-efficacy in a positive way?
- Are there any other courses/experiences that are contributing to your engineering self-efficacy in a negative way?
- What do you consider the three most important things that you learned in this class and why?
- Are there any aspects of this course that you would change? If so, please describe.

Appendix B - Open Ended Questions Analysis

Survey 1:

What do you consider the three most important things you will learn in this class and why?

Response	**Frequency**
Working/collaborating with a team	19
Engineering Design Process	15
Communication (with classmates & clients)	12
Technical Skills	11

How do you think this course will help you grow as an engineering student?

Response	**Frequency**
Exposure to ‘real world’ engineering	17
Using the Engineering Design Process	7
Increase creativity/innovation	6
Working/collaborating with a team	4

What has been the most challenging aspect of STEM coursework thus far and why?

Response	**Frequency**
Math	10
Transition from memorization to critical thinking/theory-based learning	6
Self-teaching concepts from textbooks to supplement lectures	4
Time management	3

What part of this course are you most concerned about performing well in and why?

Response	**Frequency**
Actual building/prototyping of the product	11
Applying learned technical skills	6
Creating successful product for the client	4
Working well in teams	2

What skills would you like to develop most in this course and why?

Response	**Frequency**
Technical Skills	14
Communication skills	11
Teamwork	6
Creativity	2

Survey 3:

What is currently the most difficult STEM course you are taking and why?

Response	Frequency
Math	26
Physics	4
EGR 103	3

Is it difficult because of concepts, workload, etc.?

Response	Frequency
Concepts	13
Workload	8
Pace	5

Where have you found your greatest sense of community at Duke so far?

Response	Frequency
Dorm	17
EGR 190	8
Extracurriculars	4

Has the EGR 190 class contributed to your sense of community? Why or why not?

Response	Frequency
Yes	27
No	2

Why or why not?

Response	Frequency
Small Groups	9
Like-minded Classmates	4

Self-efficacy is defined as one’s belief in one's ability to achieve a specific task or succeed in a particular area by achieving the intended results. In the context of this course, has it contributed to your engineering self-efficacy positively, negatively, or not at all? Why?

Response	Frequency
Positively	27
Negatively	0
Not at all	0

Why?

Response	Frequency
Increased Confidence	18
Gained Technical Skills	11
Provides Real-World Engineering Experience	3

Are there any other courses/experiences that are contributing to your engineering self-efficacy in a positive way?

Response	Frequency
EGR 103	14
Nothing Else Contributes Positively	7
Math	3

Are there any other courses/experiences that are contributing to your engineering self-efficacy in a negative way?

Response	Frequency
Nothing Else Contributes Negatively	14
Math	7
Physics	3

What do you consider the three most important things that you learned in this class and why?

Response	Frequency
Working/collaborating with a team	24
Engineering Design Process	12
Communication (with classmates & clients)	10
Technical Skills	11

Are there any aspects of this course that you would change? If so, please describe.

Response	Frequency
Start the actual project/prototyping process sooner	11
Less technical memos	5
Clearer/better defined grading	3

Appendix C – Demographic Information

Gender Identification	Percentage of Respondents	Percentage of Class
Male	48.2	58.3
Female	51.8	39.6
Racial Identification	**Percentage of Respondents**	**Percentage of Class**
Majority	69.2	70.8
Underrepresented Minority	30.8	27.1

Appendix D - Focus Group Questions

- If you were telling a friend about your time so far in the school of engineering, how would you describe it to them?
- For those of you who want to major in engineering – what drew you to the field and what (if anything) intimidates you about the field?
- Why do you think a student might decide to pursue engineering at Duke, or not?
- What is currently the most difficult STEM course you are taking and why?
    - *Define what difficult is (lots of work vs. intellectually challenging)*
- Tell me about a positive experience you have had so far in the course.
- Tell me about a negative experience you have had so far in the course.
- What have you learned about the engineering design process and how do you think you could apply that process to other problems?
- What do you think when you hear the term "self-efficacy"? How does that relate to pursuing engineering? What do you think contributes to someone's academic or engineering self-efficacy?