2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #32970

Mechanical Engineering Students' Perceptions of Design Skills Throughout a Senior Design Course Sequence

Valerie Vanessa Bracho Perez, Florida International University

Valerie Vanessa Bracho Perez is a Master of Science in Mechanical Engineering student and Graduate Research Assistant in the School of Universal Computing Construction and Engineering Educations (SUCCEED) at Florida International University (FIU). She also holds a Bachelor's degree in Mechanical Engineering from FIU. Her research interest includes integrating LAs into engineering courses, examining responsive teaching practices in engineering courses, and faculty development.

Anilegna Nuñez Abreu, Florida International University

Anilegna Nuñez Abreu is a Mechanical Engineering undergraduate at Florida International University. With a year of industry internship experience, her professional interests include systems engineering and human-centered design. In addition, Anilegna's research interests include improving engineering design practices, integrating culturally responsive teaching, and raising engineering retention rates within academia.

Mr. Ameen Anwar Khan, Florida International University
Luis Enrique Guardia, Florida International University

Luis Enrique Guardia is a Master of Science in Biomedical Engineering student and Graduate Assistant in the School of Universal Computing Construction and Engineering Education (SUCCEED) at Florida International University (FIU). Luis also holds a bachelor's degree in biomedical engineering from FIU and is particularly interested in the intersect between medicine, engineering, and learning. His research interests include empathic teaching and learning, mentorship relationships, and improving stakeholder considerations in students.

Indhira María Hasbún, Florida International University

Indhira María Hasbún is a Ph.D. candidate and Graduate Assistant in the School of Universal Computing, Construction, and Engineering Education (SUCCEED) at Florida International University (FIU). Her research analyzes the interplay between institutional structures, culture, and agents at Hispanic-Serving Institutions (HSIs) to identify how colleges of engineering at HSIs can leverage their institutional systems toward educational transformation as they pursue their goals of serving undergraduate Latinx engineering students.

Dr. Alexandra Coso Strong, Florida International University

As an assistant professor of engineering education at Florida International University, Dr. Alexandra Coso Strong works and teaches at the intersection of engineering education, faculty development, and complex systems design. Alexandra completed her doctorate in aerospace engineering at Georgia Tech. Prior to attending Georgia Tech, Alexandra received a bachelor's degree in aerospace engineering from MIT and a master's degree in systems engineering from the University of Virginia. Alexandra comes to FIU after completing a postdoctoral fellowship at Georgia Tech's Center for the Enhancement of Teaching and Learning (CETL) and three years as a faculty member at Olin College of Engineering in Massachusetts. Alexandra's research aims to amplify the voices and work of students, educators, and Minority-Serving Institutions (MSIs) overall and support continued educational innovation within engineering at these institutions. Specifically, she focuses on (1) educational and professional development of graduate students and faculty, (2) critical transitions in education and career pathways, and (3) design as central to educational and global change.

Mechanical engineering students' perceptions of design skills throughout a Senior Design course sequence

Abstract

Engineering design requires high-level, interdisciplinary, collaborative problem-solving skills to successfully solve complex and dynamic challenges. For this reason, engineering design courses have served as a platform for educators to provide students with skills and experiences to face the global challenges they will encounter in their careers. This study examines students' perceptions of and reflections on the skills developed throughout the courses taken throughout their undergraduate engineering curriculum. Students in a senior design sequence were surveyed during each semester of the course about their perceptions of senior design and the skills and previous courses that were most relevant to design. The study was conducted within a large, public, MSI over the course of five semesters of the Mechanical Engineering Senior design sequence. Relationships between particular course groups and the skills students perceived as important for design were found. The results demonstrate that students perceived Engineering Core Courses, Engineering Design Courses, and Engineering Track Core Courses as important in preparing them for senior design. In addition, correlations between the courses mentioned and the skills students considered important for design or were confident in using in design illustrated influential components of the curriculum. Some of these skills included: written communication, programming, hands-on building, teamwork, project management, using machine shop tools, and oral communication. Students' resulting perceptions of which skills are "very important" and which they are "very confident in" design suggest the need to explore alternative assessment methods. Alternatively, these results may illustrate gaps in the existing curriculum around particular skill development and areas where faculty may want to foster students' understanding of and the skills necessary for design. Overall, this study aims to inform researchers and educators about the type of courses that may impact students' skill development and understanding of design to serve as a basis for designing more student-centered engineering curricula.

Motivation

Design courses serve as a platform for students to exercise and gain the skills necessary to undertake the complex and dynamic challenges they will encounter in their careers. Engineering design is a flexible and creative problem-solving process; it is not an exact science and requires the need to empathize, thoroughly define, and creatively ideate for the situation at hand [1], [2]. The skills exercised in design, and in these design courses, can be effectively translated to any role within engineering, as design requires a mixture of technical and professional skills.

However, despite the similarities that design courses may offer to real-world experiences, educators face challenges balancing what the curriculum can simulate (e.g., realistic design constraints, access to stakeholders) and what would be most helpful in developing students for the complex, multidisciplinary work environment they will enter after graduation [3]. As such, there is currently a gap between what educational opportunities are feasible within academia versus what is required to excel in collaborative, multidisciplinary design environments. This gap has been echoed in current literature through discussions of the need to enhance professional skills such as communication and teamwork [4]. Nevertheless, researchers argue that there is still a need to develop empirical representations of engineering work and engineers in practice to help engineering educators design curricula for students [5]. Yet, while studies have investigated the skills students develop in design, research is limited in focus to the design courses themselves [6], [7].

The capstone senior design courses are among the main areas in the curriculum where students develop design skills, integrate technical knowledge from previous courses, and further their professional skills. There is, as a result, an opportunity to examine students' perceptions of their skill development across the entire curriculum and possibly leverage the entire curriculum to develop critical design, technical and professional skills. According to research, only deliberate practice, practice done with the intention of improving a skill, will lead to expertise [1]. Therefore, investigations about which courses successfully impact students' design skills can be valuable to design educators and all educators who work with engineering students design.

Studies have shown that understanding students' perceptions of their learning and skills is essential for determining how their education has impacted their knowledge and skill development [8]. However, studies on design skills in capstone senior design courses are limited in their understanding of the factors that affect a student's perception of the skills that are important for engineering design practice [9], [10], [11], indicating that there is a need to further understand what factors influence engineering students' perceptions of design skills. Additionally, there is a gap between what engineering students and practicing engineers believe engineering work, design, and practice to be, demonstrating a need to understand the representations students have of engineering, design, and engineering practice [5].

The study presented in this paper is part of a larger project exploring the overall student experience within a redesigned senior design mechanical engineering capstone course at a large, public, Minority Serving Institution (MSI). This study highlights students' perceptions of the skills developed, and courses taken throughout their undergraduate engineering curriculum. Like practicing engineers, students draw from what they have learned during their undergraduate experiences and other areas to inform their design approach. Therefore, understanding students' perceptions, the skills they are developing across the curriculum, and the factors influencing said skill development is essential in designing student-centered engineering design curricula. Ultimately, we seek to support the design of engineering curricula that is supportive of students' development as engineers, as they prepare to face the increasingly complex and multifaceted challenges seen in society.

Background

Existing research emphasizes the need to develop students' design skills in ways that will best prepare them for their future careers. Within design, researchers and educators acknowledge the complexity of the products and systems that engineering graduates will design and need to design in the future [5], [12], [13]. The challenges faced by students upon graduation are likely to involve what Stevens and Johri (2013) call "complex, large-scale sociotechnical systems" (p.

130), echoing Brunhaver and colleagues (2018) description of these possible challenges as "complex, ambiguous, and political" (p. 132). As a result, researchers have examined engineering practice to better articulate the wide range of skills needed for engineering graduates to be successful in their work (e.g., [9], [14]–[19]). In addition, researchers have engaged with industry members to better articulate the core competencies necessary for early-career engineers [20], [21]. Overall, across the literature, there is an expectation that entry-level engineers be well equipped with both technical and professional skills such as project management, teamwork skills, leadership skills, and communication to enable them to successfully tackle the complexity of design challenges [13], [17].

However, in a study of engineering juniors, Brunhaver and colleagues (2018) reported that "many engineering students hold the unrealistic view that engineering is synonymous with technical problem solving even after they have completed design projects (such as senior capstone) in upper-division courses*"* (pg.152) [13]. This finding contrasts the complex view of engineering design and practice that researchers illustrate. As engineers continue with their careers, the importance of professional skills increases, as compared with technical skills and technical problem-solving skills [9], [13], [17]. Similarly, other studies indicate that students have "vague images of professional engineering work," and the images they do have are strongly impacted by their experiences during their educational careers [4, pg. 120] Stevens and colleagues state that "students often ignore, discount or simply do not see images of engineering that emphasize its non-technical, non-calculative sides and its non-individual aspects " [4, pg. 120]. Furthermore, Stevens and colleagues (2013) argue that there is a need to develop empirical representations of engineering work and engineers in practice to help engineering educators design curricula for students. Therefore, in considering the curricular designs of engineering design courses, it becomes crucial to further understand students' perceptions of important skills in engineering design and experiences that impact their perceptions.

Existing studies of design skills within capstone and senior design courses are limited in their understanding of the factors affecting a students' perception of the skills that are important or necessary for engineering design practice. For example, researchers have used *the student ranking of importance of design activities* question with design students to focus on changes in perceptions over time (e.g., [9], [10], [11]). Yet, these studies do not reflect on particular factors that may have impacted students' perceptions. Others focus on students' performance and behaviors within a senior design course and how those illustrate what skills students perceive as important to design (e.g., [3], [22]). While valuable to capturing students' actions, these studies are limited in their focus on potential factors affecting students' perceptions at the start of a senior design sequence. Whether in how educators design courses or how programs examine students' learning and skill development across the curriculum, understanding students' prior knowledge and their perceptions of their learning and skills is essential for supporting evidence-based changes to courses and programs [8]. Ultimately, there is a need to further understand what factors influence engineering students' perceptions and development of design skills so that they are better prepared to solve increasingly complex problems and global challenges across cultural, disciplinary, and geographic boundaries.

Nonetheless, a few studies have indicated that educational experiences, among others, are factors that influence an engineering students' development of design skills (e.g., [13], [18], [23]). For example, Krause and colleagues (2013) distributed a playground design task to different designers with varying levels of expertise. Results indicated that domain expertise, which was critical to the designers' performance on the task, was developed through professional and educational experiences. In an earlier study, Atman and colleagues (2008) demonstrated a relationship between students' educational experiences in design and engineering and their internalization and use of engineering design language. For those students with design experience or in later parts of the engineering curriculum, they demonstrated the design expertise they had developed over time. Lastly, Brunhaver found that "when ask[ed] where they learned the knowledge and skills they considered important, the [student] participants said they learned math and science in the classes they had been taking since elementary school," which further points to how educational experience can profoundly impact a designer's design skills and which skills they believe are important (pg.144) [10]. Still, few studies provide a detailed understanding of where students are developing these skills and these perceptions in their engineering programs. Hence, there is a need to examine students' perceptions of their skill development and the factors that impact their perceptions. Therefore, the study presented in this paper begins to examine which courses prepare students with design-relevant skills to better support them as they develop the skills necessary to succeed in the workforce.

Methods

Overview

The research presented in this paper is part of a larger investigation aimed to examine students' overall perceptions and experiences within their design curriculum. Specifically, this paper aims to highlight students' reflections on the skills and courses that are most relevant to their senior design experience. Data from surveys conducted in senior design courses were analyzed to examine students' perceived confidence and importance of various design skills while cross-analyzing these perceptions with the courses they have found to be relevant in their preparation for their design capstone course. Overall, this study is guided by the following research question: *How do the perceptions of mechanical engineering students' design skills evolve throughout the course of a senior design course sequence?*

Site and Sample

This research is currently being conducted at a large public Minority Serving Institution (MSI) in the southeastern United States. In 2019, the mechanical engineering department engaged in a complete redesign of its senior design course sequence. The motivation for the redesign was multifaceted: (1) increase the number of client-based projects and industry-partnerships in the course, (2) scaffold aspects of the problem definition phase of design in the first semester of the course, (3) increase support for student teams throughout the project, and (4) engage students in thinking more explicitly about the implications of their work. The redesigned version of the course is divided across two semesters, Senior Design 1 (SD 1) and Senior Design 2 (SD 2).

Only one section of each course is offered every semester and is co-taught by 3 to 4 engineering faculty. While the same 1 to 2 faculty remain part of the course each semester, the other faculty rotate in or out pending their teaching requirements. However, the structure of the courses remains the same every semester, with minor adjustments being made in response to student feedback which includes the results of our broader research study.

SD1 is a lecture- and workshop-based course that allows students to participate in in-class activities and engage in individual and group assignments that were designed to strengthen their design skills and further expose them to new concepts within engineering design. At the start of SD1, students are introduced to various client-based projects in which they will complete within a year. The students are then placed in based on their project preferences. During SD2, students continue to participate in some in-class activities focused on their project. However, most of the time spent in class is given to the students to work on their project and consult with their project mentors. The course sequence concludes with a poster session where students share their accomplishments with the community.

Data has been collected over four semesters since the redesign. The study participants are divided into cohorts based on when participants enrolled in SD in the academic year. This paper focuses on four cohorts: Cohort 1A, 1B, 2, and 3. Further indication of when each cohort took SD 1 and SD 2 can be seen in **Figure 1**. The survey was distributed to each cohort, once in SD 1 and once again while enrolled in SD 2. Cohort 0 took the first course in the sequence prior to the redesign and was only surveyed when students were in SD 2; therefore, their responses will not be included in this study. Similarly, those in Cohort 4 taking SD 1 have only taken the survey once.

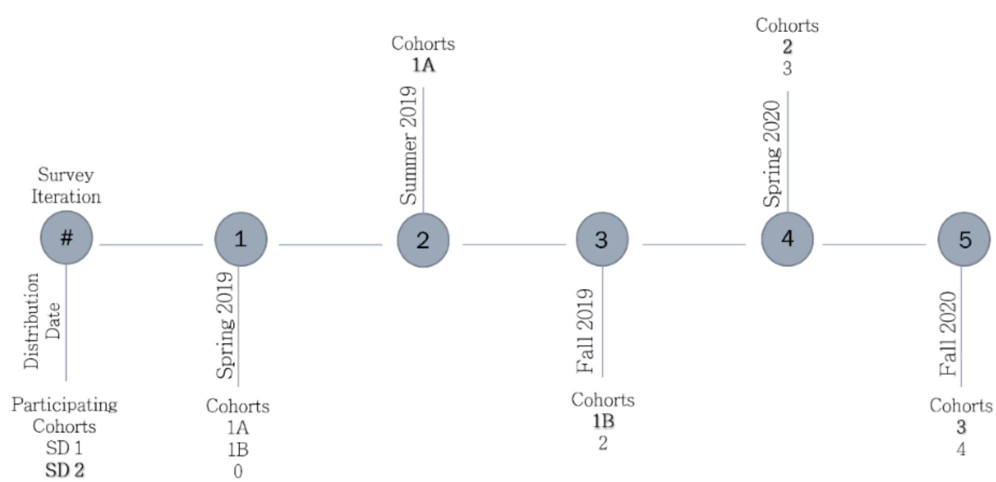

Figure 1 *Cohort and Survey Distribution Timeline*

As this is a MSI, assuring the survey sample was representative of the university population was a priority. **Table 1** represents the sample distribution across demographic variables of all research participants for this study.

Table 1 *Demographic Information of Survey Respondents*

	Respondents (%)
Male	81.8
Female	18.2
American Indian or Alaska Native	0
African American or Black	13.0
Native Hawaiian or Oher Pacific Islander	3.7
White	79.6
Multiracial	3.7
Hispanic or Spanish Origin	78.6
Non-Hispanic or Latino or Spanish Origin	21.4

Data Collection

A survey was administered at the halfway point (6th-7th week of a 14-week term) of an academic semester as part of a mid-semester feedback opportunity. The survey was distributed via a Qualtrics online survey tool link provided by the course's respective professors. Students were asked to complete the survey either during provided class time or in their own time. Responses were not mandatory, nor was there any credit or academic incentive for completion of the survey. The survey was presented as both a research opportunity and part of the continual evaluation of the redesign. The aggregated analysis of the data collected was then shared with the course instructors as part of mid-semester feedback. Students were given the option to opt-out of having their responses shared for research purposes for both surveys. Therefore, while 60% percent of students responded to the survey, only 38% percent agreed to share their responses. Of these responses, only participants matched across both SD 1 and SD 2 were included in this study. Based on this criterion, responses from a total of 56 students were analyzed.

Survey Instrument and Variables

This paper focuses specifically on a sub-section within the survey where students share their experiences about senior design. From this section, the analysis of the three following questions are the basis of this paper: (1) *"Which courses leading up to Senior Design best prepared you for this class?"*, (2) *"How important are the following skills for engineering design projects, in general?, and* (3) *"How confident are you in your skills in each of these areas?"*.

Question (1) was an open-ended question, while questions (2) and (3) asked students to rate the same ten skills on three-point Likert scales based on their perceived level of importance and confidence, respectively. A three-point Likert scale was chosen due to the exploratory nature of this study. We were interested in seeing students' initial perceptions, particularly examining whether the students' responses were above or below the middle value of the scale, rather than gauging the intensity of the response. Additionally, the skill set used in the survey was developed specifically for this population and the specific skill needs within this senior design course. The team examined previous research on students' understanding of critical design skills as they developed the survey [23]–[26] **Table 2** presents an example of question (2) alongside the ten skillset areas students were asked to evaluate (1 corresponding to "not at all important," 3 corresponding to "very important").

Table 2 *Survey Items Used as Variables in this Study*

Question: How important are the following skills for engineering design projects, in general?[a]
Modeling and Simulation
Programming
Hands-on building
Using Machine Shop Tools
Written Communication Skills
Oral Communication Skills
Project Management
Leadership
Teamwork Skills
Accounting/Conducting Cost Analysis

[a]1: least important; 2: somewhat important; 3: very important.

Data Treatment and Preparation

The data was analyzed using IBM's Statistical Package for the Social Sciences (SPSS) Software. As part of the data cleaning process, missing data and outliers were removed from the dataset on a question per question basis. The dataset was determined to be not normally distributed; therefore, non-parametric tests were utilized.

Analysis

To understand which courses best-prepared students for SD, participants' responses to Question (1) were analyzed using open coding [27], [28]. Each course a participant mentioned was used to develop overarching course classifications that could be used to describe the components of a mechanical engineering curriculum: University Core, Engineering Pre-requisites, Engineering Core, Engineering Track Core, Engineering Electives, and Design courses. Of these courses, Engineering Core and Engineering Pre-requisite Courses are the only groups of courses that all students within the mechanical engineering program must take. There is more variation in what students take within the other course groups. For example, in Engineering Track Core courses, students can decide what courses they will take, provided they meet the requirements for the laboratory requirement for the mechanical engineering program. Further details on the criteria of each course classification are illustrated in **Figure 2**. After each response was sorted, NVivo was utilized to obtain descriptive statistics on the data.

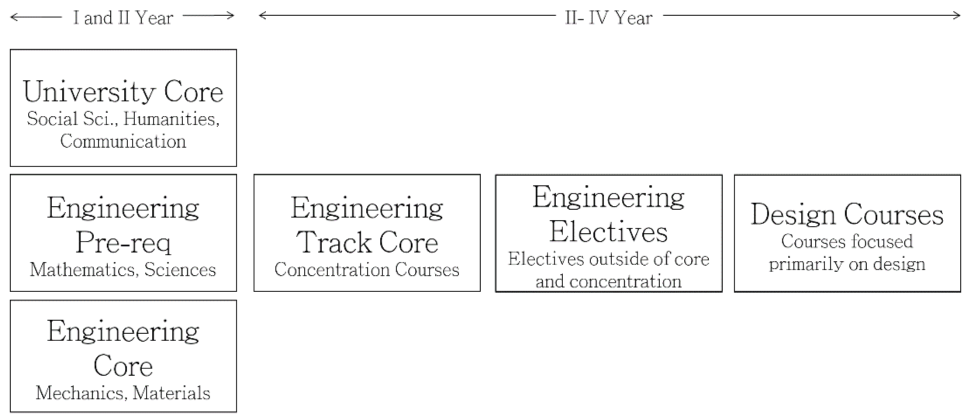

Figure 2 *General Engineering Curriculum and Course Classifications*

Following the course analyses, Mann-Whitney tests were run to test for differences between 1) students' perceived level of importance in each design skill versus each course classification and 2) students' perceived level of confidence in each design skill versus each course classification. These tests were run independently in both SD 1 and SD 2. Comparisons were made between participants who mentioned a particular group of courses to be important in Senior Design and those that did not mention that same group of courses as important in Senior Design. This comparison was made to gauge if there were any significant relationships between the group of courses students considered to be important in senior design and the skills they believe were important in design or had confidence in using in design. The p-value used to determine statistical significance for all tests was $p<0.05$.

Limitations

The results reported in this study should be seen in light of some limitations. This study presents the results of students who opted to have their responses utilized for research purposes; thus, the data presented is not fully representative of the data collected from all students who responded to the survey. Additionally, since this study was conducted across multiple semesters, there were missing data resulting from students who potentially chose not to participate in the survey during one of its iterations. It should also be noted that two of the authors have a relationship to the course directly. One of the authors is an instructor for two cohorts, which may have impacted participants' responses and participation. The other was a student in one of the cohorts. Their responses were not included within the research study as a result. With respect to the survey structure, the 3-point Likert scale may have restricted student's reflection as it only allowed for polar points or a neutral option when describing their level of importance or confidence.

Results

Overview

To explore the relationship between students' perceived level of importance/confidence in particular design skills and the courses they perceived were important during Senior Design. Mann-Whitney tests were run to test for differences between 1) students' perceived level of importance in each design skill versus each course classification and 2) students' perceived level of confidence in each design skill versus each course classification.

Due to the extensive number of tests run, the results presented in this section are only those for which the Mann-Whitney tests yielded statistically significant results (i.e., 10 skills x 6 course groups x 2 SDs, yielding 120 tests for confidence and importance). However, we have constructed **Table 3** to provide descriptive statistics for each skill and group of courses.

Perceived Importance and Confidence in Skills within Design

As shown in **Table 3** during SD1, the perceived level of importance of using machine shop tools in design had the highest mean (M=1.52), while the perceived level of importance of using teamwork skills in design had the lowest mean (M=1.04). Additionally, students perceived level of confidence in using programming skills in design during SD1 had the highest mean (M=2.04). In contrast, the perceived level of confidence in using teamwork skills in design had the lowest mean (M=1.23). As shown in **Table 3** during SD2, the perceived level of importance of using machine shop tools in design had the highest mean (M=1.63), while the perceived level of importance of using teamwork skills in design had the lowest mean (M=1.02). Additionally, students perceived level of confidence in using programming skills in design during SD2 had the highest mean (M=2.05). In contrast, the perceived level of confidence in using written communication skills in design had the lowest mean (M=1.16).

Table 3: *Perceived Importance and Perceived Confidence in Using Skills in Design for SD1 and SD2 (n=56)*

Skills	**Perceived Importance in Using Skill in Design**						**Perceived Confidence in Using Skill in Design**					
	Mean		**Std. Deviation**		**Median**		**Mean**		**Std. Deviation**		**Median**	
	SD1	***SD2***	***SD1***	***SD2***	***SD1***	***SD2***	***SD1***	***SD2***	***SD1***	***SD2***	***SD1***	***SD2***
Modeling and Simulation	1.09	1.04	0.288	0.187	1	1	1.43	1.32	0.535	0.471	1	1
Programming	1.48	1.62	0.572	0.59	1	2	**2.04***	**2.05***	0.631	0.616	2	1
Hands-on Building	1.38	1.43	0.489	0.499	1	1	1.36	1.52	0.554	0.603	1	1
Using Machine Shop Tools	**1.52***	**1.63***	0.539	0.59	1.5	1	1.78	1.82	0.802	0.69	1	1
Written Communication	1.18	1.09	0.431	0.288	1	1	1.3	**1.16+**	0.537	0.371	1	1
Oral Communication	1.11	1.09	0.312	0.288	1	1	1.36	1.32	0.554	0.471	1	1
Project Management	1.12	1.07	0.334	0.26	1	1	1.43	1.45	0.535	0.571	1	1
Leadership	1.27	1.2	0.486	0.401	1	1	1.43	1.48	0.568	0.572	1	1
Teamwork Skills	**1.04+**	**1.02+**	0.187	0.134	1	1	**1.23+**	1.25	0.467	0.513	1	1
Accounting/ Conducting Cost Analysis	1.50	1.55	0.572	0.57	1	2	1.63	1.54	0.558	0.602	2	1
Bolded numbers indicate numbers that were mentioned in the text *Indicate the highest mean in SD1 and SD2 +Indicate the lowest mean in SD1 and SD2												

Perceived Importance of Prior Coursework in Senior Design

Table 4 shows how frequently particular groups of courses were mentioned as being important for SD1 and SD2, respectively. During SD1, Engineering Core Courses were most frequently mentioned, with 46 participants mentioning that those courses were important during SD1, while Engineering Pre-requisite Courses (e.g., math, science) were not frequently mentioned, with 1 participant mentioning that those courses were important in SD1. The same results were seen in SD2, with 48 participants mentioning that Engineering Core Courses were important during SD2, and 3 participants mentioning that Engineering Pre-requisite Courses were important in SD2.

Table 4: *Frequency of Mentions per Course Group*

Courses	Number of participants who perceived course group as important in SD1 (n=54) and SD2 (n=55)	
	SD1	SD2
University Core Courses	2	6
Engineering Pre-req Courses	**1***	**3***
Engineering Core Courses	**46***	**48***
Engineering Design Courses	25	23
Engineering Elective Courses	4	9
Engineering Track Core Courses	15	13
Bolded numbers with asterisks (*) indicate numbers that were referenced in the text		

Perceived Importance of Skill in Design vs. Curriculum Courses

Mann-Whitney tests were run to test for differences between how important students perceived a particular skill was in design during each course within the sequence and how important students perceived groups of courses in their curriculum. These results can be found in **Table 5**.

Table 5*: Perceived Importance of Skill in Design*

	SD1				SD2			
	n	Mann-Whitney		p	n	Mann-Whitney		p
		U	z			U	z	
Perceived Importance of Skill in Design								
Engineering Elective Courses								
Teamwork Skills	54	77	-2.322	<0.020				
Engineering Track Core Courses								
Using Machine Shop Tools	54	190.5	-2.022	<0.043				
Oral Communication					55	223	-1.989	<0.047

Perceived Importance of Skill in Design vs. Curriculum Courses in SD1

The relationship between the following group of courses and perceived importance of particular skills in design resulted in statistically significant results with $p<0.05$ for SD1: 1) Teamwork Skills and Engineering Elective Courses, and 2) Using Machine Shop Tools Skills and Engineering Track Core Courses. These results can be found in **Table 5**.

Students who perceived Engineering Elective Courses were important during SD1, on average, perceived teamwork skills as more important. Engineering Elective Courses offer a wide range of courses with varying course structures (i.e., many courses may require group work in-class). These varying course structures may allow students to work in groups and develop teamwork skills, which may impact a students' perceived importance of teamwork skills in design.

Students who perceived Engineering Track Core Courses were important during SD1, on average, perceived using machine shop tools skills as more important. Engineering Track Core Courses offer students the chance to concentrate on a specific area of mechanical engineering. In the mechanical engineering curriculum from this study, one of the concentrations available to students has a laboratory component that requires students to become familiar with using machine shop tools. Additionally, other concentrations in the mechanical engineering curriculum also have a laboratory component that requires students to work with machinery. However, 8 out of the ten skills tested did not yield a statistically significant relationship with any of the courses, which may indicate that the courses are not providing the support the students need to build these skills or are not emphasizing these skills enough for students to deem them important.

Perceived Importance of Skill in Design vs. Curriculum Courses in SD2

The relationship between the Engineering Track Core Courses and the perceived importance of oral communication in design resulted in statistically significant results with $p<0.05$. These results can be found in **Table 5**.

Students who perceived Engineering Track Core Courses were important during SD1, on average, perceived oral communication skills as more important. Examining the mechanical engineering curriculum at the research site, there is no easily observable rationale for this result. Future investigation into the curricular components of these courses may be warranted.

Perceived Confidence in Using Skill in Design vs. Curriculum Courses in SD1 and SD2

Mann-Whitney tests were run to test for differences in the extent to which students perceived confidence in using a particular skill in design and the extent to which they perceived specific courses were important for Senior Design. These results can be found in **Table 6**.

***Table 6**: Perceived Confidence in Using Skill in Design*

	SD1			
	n	Mann-Whitney		p
		U	z	
Perceived Confidence in Using Skill in Design				
University Core Courses				
Written Communication Skills	54	7.5	-2.611	<0.009
Engineering Pre-requisite Courses				
Written Communication Skills	54	15	-2.171	<0.030
Engineering Core Courses				
Programming Skills	54	111.5	-2.056	<0.040
Hands-on Building Skills	54	112.0	-2.129	<0.033
Teamwork Skills	54	120.0	-2.159	<0.031
Engineering Design Courses				
Project Management Skills	54	255.5	-2.168	<0.030

Perceived Confidence in Using Skill in Design vs. Curriculum Courses in SD1

The relationship between the following group of courses and the students perceived confidence in using particular skills in design resulted in statistically significant results with $p<0.05$: 1) Written Communication Skills and University Core Course, 2) Written Communication Skills and Engineering Pre-requisite Courses, 3) Programming Skills, Hands-on Building Skills, Teamwork Skills and Engineering Core Courses, 4) Project Management Skills and Engineering Design Courses. These results can be found in **Table 6**.

Students who perceived University Core Courses were important during SD1, on average, had more perceived confidence in using written communication skills in design. University Core Courses consists of courses in the fields of humanities, social studies, and communication. These courses typically have an intensive writing component, allowing students to practice and develop their writing skills, possibly allowing them to develop confidence in their written communication skills.

Students who perceived Engineering Pre-requisite Courses were important during SD1, on average, had more perceived confidence in using written communication skills in design. Courses within the Engineering Pre-requisite Courses consist of general core science and math courses such as physics and chemistry. These courses may require that students take laboratory components, specifically the science courses. In these laboratory courses, students must complete lab reports on the experiments run in the class, which may allow students to practice and develop their technical writing skills, possibly impacting a students' perceived confidence in their written communication skills.

Students who perceived Engineering Core Courses were important during SD1, on average, had more perceived confidence in using programming and hands-on building in design. Engineering Core Courses provide a range of fundamental engineering science courses that students in the mechanical engineering curriculum must successfully complete before graduation. Programming and some laboratory courses are required. In the programming course, students practice and develop programming skills, which may impact a students' perceived confidence in using programming skills. Furthermore, the laboratory courses require students to work hands-on with lab equipment and build circuits and manufacture parts, allowing them to gain hands-on experience. This curricular focus may impact their perceived confidence in using hands-on building skills.

Students who perceived Engineering Design Courses were important during SD1, on average, had more perceived confidence in using project management skills in design. Engineering Design Courses typically have design projects in them, which may require students to use their project management skills. Additionally, in the context of SD1, SD1 requires that students begin to think about how they are going to handle the different tasks within their project (i.e., includes creating a timeline of the project, dividing tasks among team members, etc.). With the project management components of these Engineering Design Courses, the students perceived confidence in using project management might be impacted.

Overall, the results from the Mann-Whitney tests are supported based on the structure and components of University Core, Engineering Pre-requisite, Engineering Core, and Engineering Design courses in mind. However, 5 of the ten skills tested did not yield a statistically significant relationship with any of the courses. This result may indicate that the courses are not providing the support the students need to practice and develop these skills so that they may gain confidence in using them.

Perceived Confidence in Using Skill in Design vs. Curriculum Courses in SD2

The relationship between groups of courses and the students' perceived confidence in using particular skills in design did not result in any statistically significant relationships. Future examination into the curricular components of these courses and the student's confidence level in using design skills during SD2 may be warranted.

Discussion and Conclusion

This paper explored students' reflections on the skills and courses that are most helpful to their senior design experience. For example, students most commonly described Engineering Core Courses, Engineering Design Courses, and Engineering Track Core Courses as important in preparing them for senior design. In addition, relationships between the courses mentioned and the skills students considered important for design or were confident in demonstrated influential components of the curriculum. These skills included: written communication, programming, hands-on building, teamwork, project management, using machine shop tools, and oral communication. However, there were very few statistically significant relationships to note. This result may indicate that the courses are not directly impacting these skills, are negatively impacting these skills, or are not emphasizing the skills within the courses. Therefore, more research is needed to understand how these courses are impacting skill development.

Of those statistically significant results, students who perceived Engineering Elective Courses as being important in design, on average, believed that teamwork skills were more important (**Table 5**). However, our results indicate that students generally did not perceive teamwork skills as important in design outside of those who perceived Engineering Elective Courses as important. Given the critical nature of teamwork and collaboration within engineering design, this result warrants additional investigation. Additional research on the structure and components of Engineering Elective courses may also benefit curricular efforts to further emphasize teamwork skill development.

Our results also indicated that student's confidence in using written communication skills in design decreased as students moved from SD1 to SD2. Considering the structure of senior design at this MSI, students typically receive a significant amount of feedback on their writing at the end of SD1. As such, this feedback may have impacted the students' perceived confidence in their written communication skills. Future work and course design could explore approaches for increasing students' confidence in their writing between SD1 and SD2 and incorporate additional support within the courses and the whole curriculum.

Looking across the skills students considered important in design, most respondents did not perceive any skills to be "very important" in design (**Table 3**). This result may suggest that it is not clear which skills are very important in design. Future work could extend studies of students' perceptions of the most important and least important design activities (e.g., [9]–[11], [24]) and incorporate the design skills examined here to better understand students' perceptions. Alternatively, qualitative interviews or other research methods could be used to understand the rationale beyond students' perceptions. Our results also indicate that students did not typically rate their confidence in using a particular skill as "very confident" (**Table 3**). Additional research is necessary to explore potential reasons for those results, including understanding the extent to which imposter syndrome may play a role, especially given the importance senior design is given within the curriculum. Studies could also further examine the courses in the curriculum and the extent to which they foster an environment in which students can practice and develop their skills.

When looking more closely at the courses students perceived as important, very few students mentioned Engineering Pre-Requisite Courses as important in SD1 and SD2 (**Table 4).** Engineering Pre-requisite courses typically provide a foundation on general science and math courses outside of the engineering context [29]. However, the topics discussed in these classes are deeply embedded in many of the Engineering Core Courses. Therefore, due to the intersection between Engineering Core Courses and Engineering Pre-requisite courses, the lower mentions of Engineering Pre-requisite courses may be explained by their relationship to and their application in Engineering Core Courses.

Overall, our study provides a foundation for discussions among educators and curriculum directors about the skills they believe students perceive as most important in engineering design and the level of confidence they wish students to have at graduation. We recommend that faculty and undergraduate curriculum committees map the courses in the curriculum based on these engineering design skills discussions and better communicate to students the skills they believe are important for students to learn within individual courses and across the curriculum. This recommendation is based on the illustration the results provided about students' lower confidence in professional skills and their perspective of critically important professional skills (i.e., teamwork) as not important for engineering design. In addition, despite recent efforts, many engineering curricula tend to focus on the development of technical skills (i.e., pre-requisite concepts that are needed for future courses) [3], [30]. The same intentionality is not afforded to professional skills. Even with ABET outcomes focused in these areas [31], mapping the curriculum based on the skills (as well as outcomes) that students need for engineering design and students' understanding of engineering design may help create a curriculum that is developmentally-focused, student-centered, and asset-based (i.e., what skills do students already bring to engineering). Moreover, doing so would foster opportunities for students to gather expertise throughout their engineering program and allow educators to evaluate student development more holistically and over time. Understanding students, the skills they acquire throughout their engineering program, and the factors that influence these skills are crucial in adapting our programs to better prepare students to face the complexities and ambiguities within engineering design.

Acknowledgments
We want to thank our research team for providing critical feedback and constant support. We also want to thank our participants for sharing their experiences in the Senior Design survey. Finally, we want to thank the instructors of the Senior Design course sequence for allowing for the distribution of the survey and helping with the distribution.

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