Utility value of an introductory engineering design course: an evaluation among course participants.

Dr. Lilianny Virguez, University of Florida

Lilianny Virguez is a Lecturer at the Engineering Education Department at University of Florida. She holds a Masters' degree in Management Systems Engineering and a Ph.D. in Engineering Education from Virginia Tech. She has work experience in telecommunications engineering and has taught undergraduate engineering courses such as engineering design at the first-year level and elements of electrical engineering. Her research interests include motivation to succeed in engineering with a focus on first-year students.

Dr. Pamela L Dickrell, University of Florida

Dr. Pamela Dickrell is the Associate Chair of Academics of the Department of Engineering Education, in the UF Herbert Wertheim College of Engineering. Her research focuses on effective teaching methods and hands-on learning opportunities for undergraduate student engagement and retention. Dr. Dickrell received her B.S., M.S., and Ph.D. in Mechanical Engineering from the University of Florida, specializing in Tribology.

Andrea Goncher, University of Florida

Andrea Goncher is a Lecturer in Engineering Education at the University of Florida. She earned her PhD in Engineering Education from Virginia Tech and focuses on teaching and learning projects in human centred design. Her research interests include text analytics, international higher education, and engineering design education.

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Abstract

This paper describes an assessment of the implementation of an engineering design class by exploring how valuable students perceive the course in subsequent years in their college experience. This study presents a short overview of students' perceptions of this course using the usefulness component of the MUSIC Model of Academic Motivation. This component refers to how useful the task is to a person's goals (e.g., undertaking a design course in order to become an engineer). We employed data collected from former course participants (Summer 2018 to Fall 2019). A survey was distributed by e-mail including Likert-type scale statements and an open-ended question on what was perceived as useful about the course. Results of this study have the potential to inform interested stakeholders about the benefits and opportunities for improvement associated with the adoption of this type of courses in the engineering curriculum.

Introduction

Introductory engineering design courses, mainly designed for first-year engineering students, have been developed around the concept of team-based projects giving the students the opportunity to practice design, problem-solving, and professional skills such as teamwork and communication. The inclusion of introductory design courses in the engineering curriculum is a fast-growing initiative that has been implemented in several universities across the US as part of multiple efforts to improve retention [1]. Still, current concerns about engineering retention and the preparation that engineering students need, demand an examination of these courses. One way to examine these courses is by exploring how students use the content included in introductory engineering design classes as they progress into successive phases of their engineering education. In this paper, we are interested in examining what aspects of a newly implemented engineering design course students value in their subsequent years in an engineering program.

The current study summarizes how course participants describe their experiences about the usefulness of the course in their successive years in their college experience (i.e. freshman, sophomore, junior, senior). We are interested in usefulness because it refers to the potential ways students believe that they can benefit from coursework [2]. This component is similar to the utility value component of the Expectancy-Value motivation theory [3] which offers one of the most effective models for understanding cognitive processes, achievement, and academic motivation. Utility value is one of the constructs in motivation theories that have been found to predict career plans in engineering [4]. Thus, the objective of this paper is to explore how students describe the usefulness of a newly implemented introductory engineering design class as they navigate their subsequent years in college.

This paper seeks to answer the following research question:

How useful do students perceive what they learned in an introductory engineering design course for their successive years in college or for what they want to do after graduation?

We aim to answer this question by analyzing survey responses from students who have taken the class since the first course implementation in the Summer 2018 semester.

Background

Introductory engineering courses are a common element in several engineering programs. There is growing recognition in research that experiences related to these courses, and the level of success in these courses, are directly related to students' achievement and retention [5-7]. While much research has been focused on students' academic achievement or performance in these courses [8-10], the role of academic motivation, specifically task value, has been less explored. Task value refers to how valuable students perceive a task, in this case introductory engineering courses, for their short or long-term goals [2]. Finding value in an activity can support interest and persistence. This assertion is supported by engineering education research evidence that links academic motivation, including task value, with students' choice to become engineers [11] and persistence in engineering [12]. In fact, some research on first-year engineering introductory courses has suggested that students' perceptions of value are highly related to their career goals [4]. In this study, we want to focus on students' perceptions of the value of an introductory engineering design course during the subsequent years in college after they have taken the class.

The Course

Engineering Design and Society (EGN2020C) is an introductory engineering course emphasizing the design process to address a societal challenge. Students practice technical skills such as solid modeling through the Onshape software, introductory programming, sensors, data acquisition using an Arduino Uno kit, 3D printing, and several hand tools including hammers, soldering kits, precision measuring calipers, and dremels as maker tools for engineering prototyping. Students complete individual and team assignments, and the final design project is completed in teams advocating interdisciplinary collaboration, implementing project management, conducting background research by identifying and locating engineering and scientific resources, and practicing more specific professional skills such and written, pictorial, and oral communication. The intended course goals include: 1) Learn techniques to solve open-ended engineering challenges; 2) Promote a culture of making by introducing solid modeling, programming, sensors, data acquisition, 3D printing, and other maker tools; 3) Build teamwork and cooperative learning skills through participation in multidisciplinary teams and active engineering project management; 4) Build professional skills in background research & written, pictorial, and oral communication methods, among others.

The course has been designed keeping in mind a balance between professional and technical skills with an emphasis on the connection between engineering and society, including active learning, and tying learning outcomes to ABET criteria. It is a one-time course, no course/sequence or prior experience is required. Most of the students who take the course are first-year engineering students however the enrollment allows students in different class standing (sophomore, junior) and students of other majors interested in switching to engineering. Currently, the course is required by some but not all engineering majors. The college of engineering offers several engineering majors and students matriculate directly to a specific discipline although they can matriculate in the college as exploratory engineering and declare a

specific major later. The class is a multidisciplinary course focused on the human-centered design process. The course was launched during summer 2018 and it was created mainly for first-year engineering students to promote early engineering design experience. For a more detailed description of the course see [13].

Framework

The usefulness value component from the MUSIC Model of Academic Motivation [2] was used as a framework for the evaluation of the course since this component refers to the potential ways students believe that they can benefit from coursework. Usefulness refers to students' perceptions of how a learning activity might be beneficial to them in the present, or the future [2]. This component is similar to the utility value component of the Expectancy-Value motivation theory [3] which offers one of the most effective models for understanding cognitive processes, achievement, and academic motivation. Students' academic motivation is usually affected by how useful they perceive the material to be for their short-term and long-term goals. Jones [2] suggests that instructors should clearly explain how course materials are related to students' goals, and should furthermore offer students opportunities to demonstrate how such materials are related to their future careers and applied in the real world. Since we were interested in exploring how useful or how well the introductory engineering design class is related to students' current or future goals, the choice of the utility value component was appropriated for the current study.

Methods

Using a multi-method approach, the focus of this exploratory study was to capture students' perceptions of value of a newly implemented introductory engineering design course. Following a cross-sectional design, during the first weeks of the Spring 2020 semester, we purposely contacted all students who had taken the class in prior semesters (i.e since Summer 2018 when the course was first offered). This is almost two years after course completion of the first group of students that have taken the engineering design class. Students who are currently taking the course (Spring 2020) were not contacted. Students were invited to assess the course experience by completing an electronic survey that included 5-point Likert-type scale questions ranking the following: the extent to which they found the course useful, enjoyable, and important; the extent to which they expected to do well in the course; and their overall perceptions related to the course learning goals. There was also an open-ended question regarding how useful was what students learned in the course for their successive years in college or for what they want to do after graduation. The focus of the current paper will be summarizing the analysis to students' responses to the questions related to the utility value of the course.

Data analysis

After the Institutional Review Board (IRB) granted approval, all students who had completed the course were invited to participate in the study. The questionnaire was distributed via e-mail to the 331 students who had been enrolled and completed the class before the spring semester, a reminder was sent a week after the first email invitation. At the data analysis time for this study, 80 (24%) students had responded to the survey and 55 students (17%) had completed the whole

survey including the open-ended question placed at the end of the survey. Descriptive statistics were analyzed to better understand participants' demographic information such as year of study, major, gender, and ethnic background. The survey was anonymous, respondents cannot be individually identified.

The survey statements used for the current study were based on existing and previously validated questions from studies in which researchers examined students' perceptions related to the MUSIC Model of Academic Motivation developed by Jones [2] and Task Value beliefs from the Expectancy Value Theory [3]. The questions were rephrased for the purpose of this study. For example, for the open-ended question, the original questions from [14] "How useful is this activity for your goals this year or in the future?" and from [15-16] "How useful is high school math for what you want to do after you graduate and go to work?" were rephrased as *"How useful is what you learned in EGN2020C for your successive years in college or for what you want to do after you graduate and go to work?*".

Descriptive statistics were analyzed for the closed-ended statements, students' scores to the quantitative items related to the usefulness value component were compared by academic year using ANOVA, and students' responses to the open-ended question were analyzed developing themes based on students' statements justifying their perceptions about how useful the course was. Qualitative responses were also divided by class standing (freshmen, sophomores, and juniors).

Results

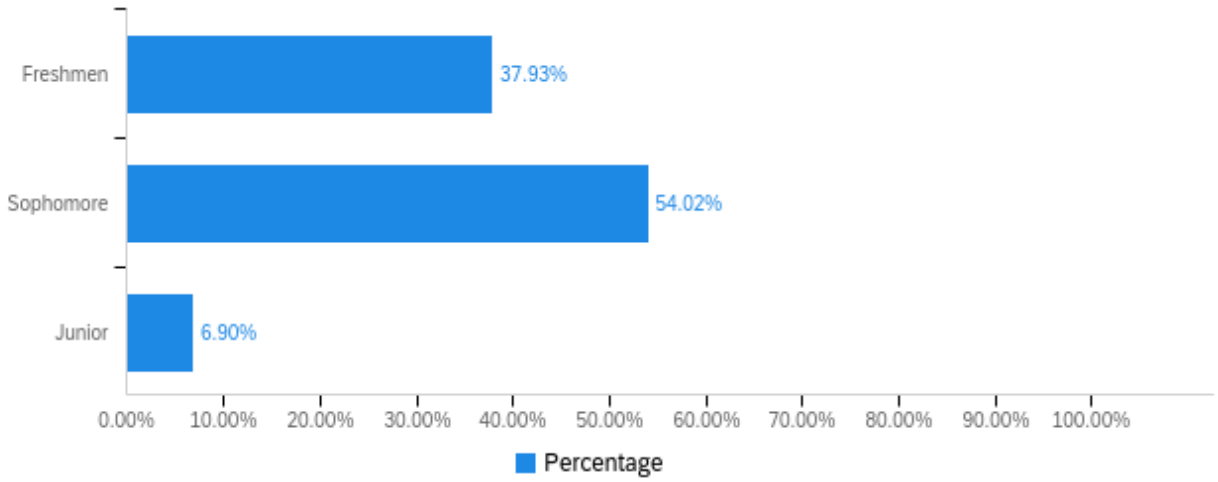

Figure 1. Respondents' distribution by current year of study (N=80)

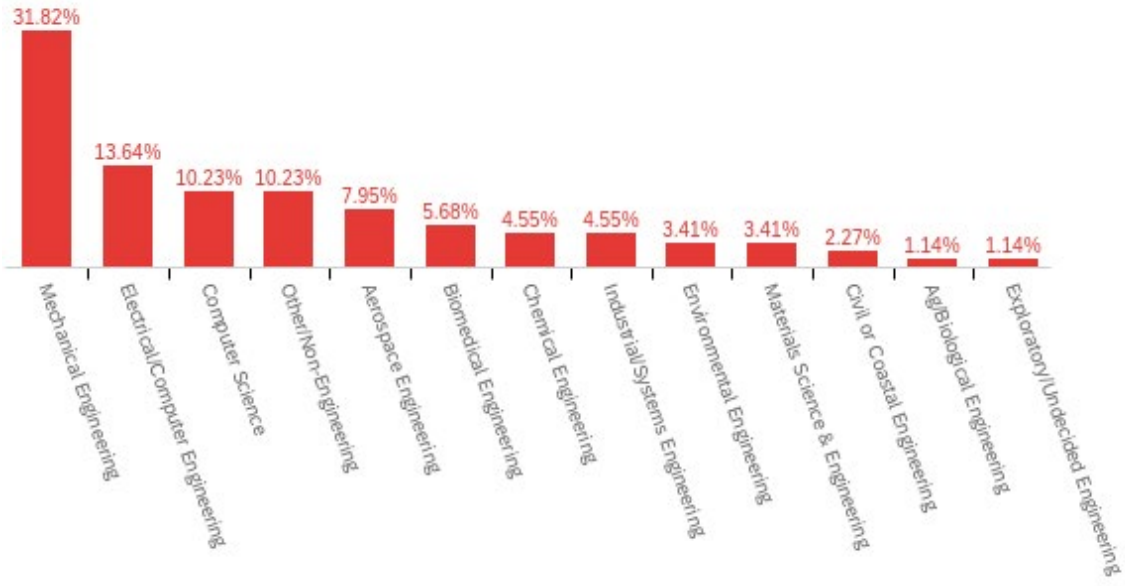

Figure 2. Participants' distribution by majors

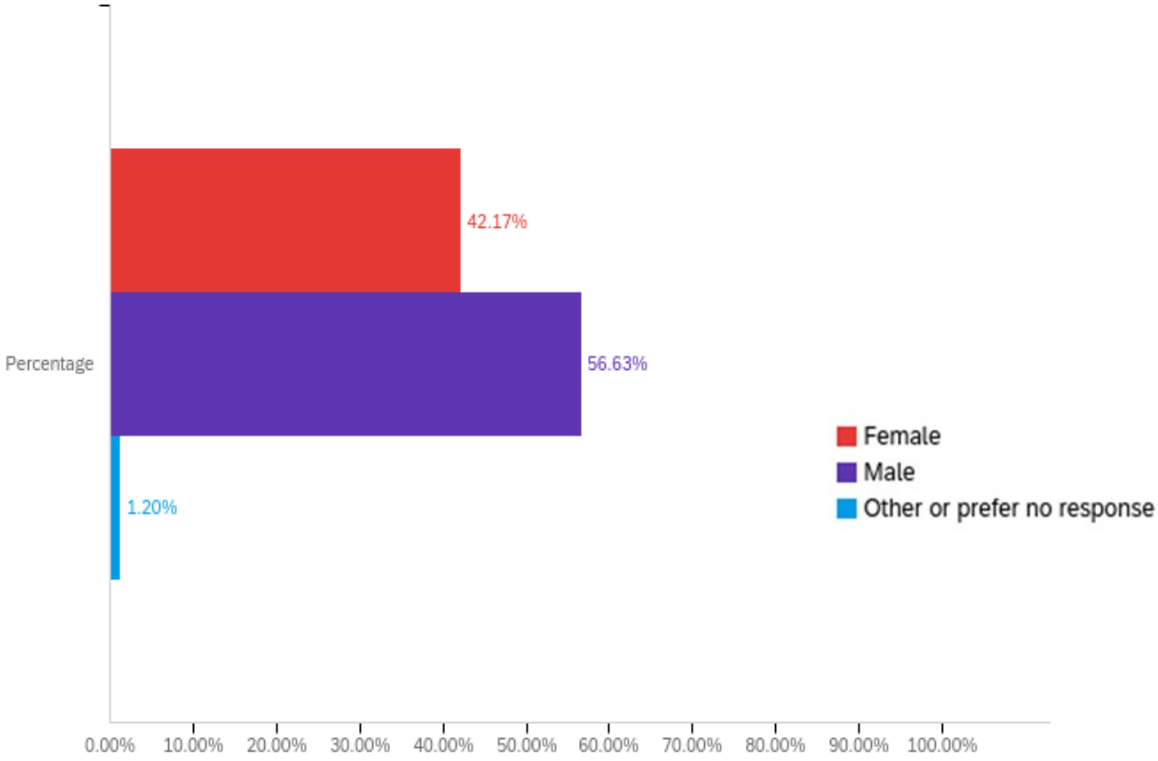

Figure 3. Participants' distribution by gender

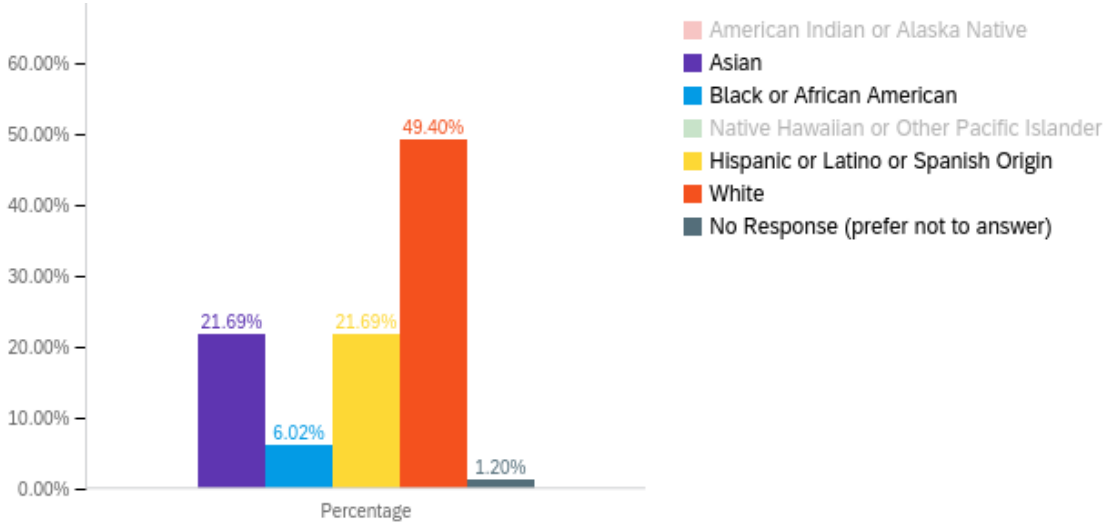

Figure 4. Participants' distribution by ethnic background

Findings

Results suggest that students have a positive utility value of the introductory engineering design class. The extent to which students found the content of the course useful was rated on a scale from "far below average" (1) to "far above average" (5). The mean for the Utility value of the course including all respondents was 3.89 and the means values by class standing resulted in freshman students (M=4.03), sophomore (M=3.73), and juniors (M= 4). We conducted a one-way analysis of variance (ANOVA) to compare the overall measure of the usefulness component among the respondents by the current year of study (freshman, sophomores, and juniors). The results of this analysis indicated that the perception of usefulness was not statistically significantly different by year in college [$(F(2,77)= 1.59$; $p= 0.21$]. Thus, the means should be interpreted according to their practical significance, the lack of significant differences may be explained by the sample size necessary to attain a certain precision or statistical significance level.

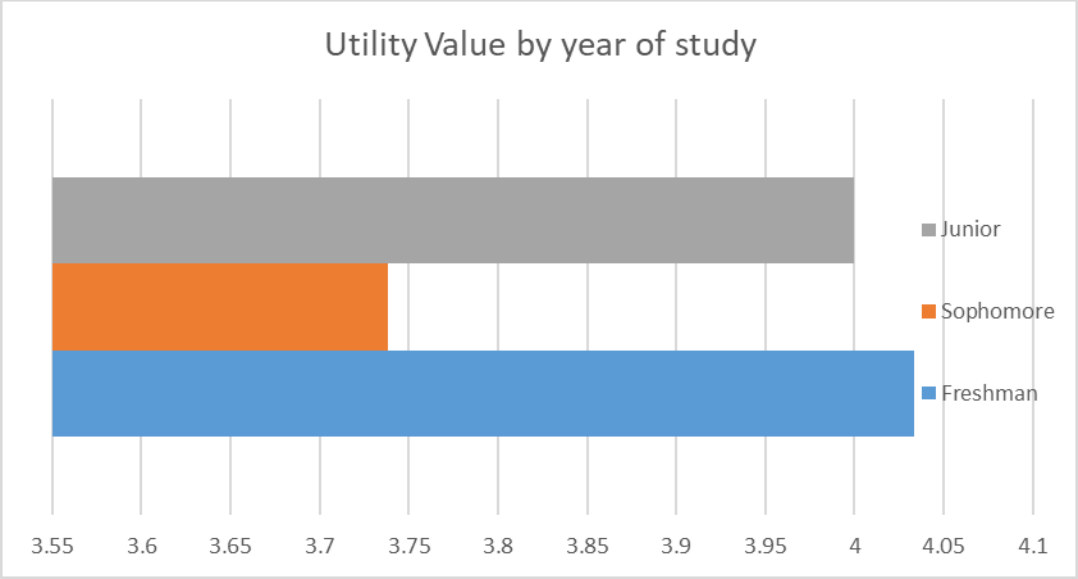

Figure 6. Mean scores for the utility value construct by year of study

We conducted a qualitative analysis of students' responses to the open-ended question, "*How useful is what you learned in EGN2020C for your successive years in college or for what you want to do after you graduate and go to work?"* We analyzed the text responses to explore how students described their experience with the class, and what reasons were given to the utility of the class and address the study's research question, *"How useful students perceive what they learned in an introductory engineering design course for their successive years in college or for what they want to do after graduation?"*

Open coding was the primary method of analysis [17] of the written-response survey question. As a starting point, the authors removed null responses from the dataset, including responses that did not have text content or had non-applicable content. We identified 25 (31% of the total responses) student responses as null responses, and they were excluded from the qualitative analysis. The open coding system helped to develop the ways students perceived usefulness and highlight key concepts found in the participant data.

During the open coding phase, individual participant responses were coded by class standing, i.e. year. The study's research question focuses on the respondents' successive years in college and after graduation, so the grouping by student's year was relevant to our analysis. We then coded the participant responses, categorized by student year, by identifying key ideas, or skills, that were prevalent in the data. Once the key ideas, or skills, were identified the initial coder categorized them under the broader, coded themes of usefulness. Table 1 provides an organized summary of the broader themes related to usefulness and examples that represent student perceptions from the data. For example, "Teamwork Skills" --related to sophomores-- encompasses responses, which highlight working in interdisciplinary groups and managing interpersonal relations.

To validate this coding process, two authors individually coded the responses. One author created the initial coding themes and categorized responses, and another author separately coded the responses using the coding themes and resolved any differences.

Table 1. Qualitative findings

Year	Coded Theme: Usefulness	Examples
Juniors	Teamwork skills	Paired up with a group of individuals Brainstorm ideas Learn new concepts from each other Simulate a real-life work experience
	Design skills	Exposed and being familiar with the design process
	Solid modeling, programming skills	Advantage in upper-level classes Circuits, problem-solving, design, ELM
	Career showcase	Internship
Sophomore	Teamwork skills	Management of interpersonal relations Working with an interdisciplinary group
	Design skills	Addressing specific problems
	Solid modeling, programming skills	Advantage in upper-level classes Solid works, microprocessors, circuits
	Contextual competence	Think like an engineer Importance of failure Real project despite lack of experience Open-ended project
	Leadership skills	Project ownership
Freshmen	Teamwork skills	Time management
	Design skills	Design process Effect of design on society
	Solid modeling, programming skills	Advantage in other classes
	Communication skills	Documentation
	Practical skills	Use of tools Skills needed for the future
	Major choice	Adjusting studies

The analysis of the open-ended question revealed that the overall perception of the utility of the course was very valuable. According to students' responses, the utility value of the course could be attributed to the acquisition of mainly three categories or skills: 1) the teamwork experience in the class; 2) experiences related to the design process, and 3) the acquisition of technical skills such as solid modeling and programming. These three skills types were in common for the three groups of students the qualitative data was divided by (freshmen, sophomores, and juniors). This finding is in line with a similar study on evaluating the perceived value of a first-year engineering experience [18].

There were some differences in the utility value of the course according to the year of study. For example, when asked about the usefulness of the course, a Junior student talked about how the introduction to solid modeling and programming in the class was useful to secure an internship during a career showcase:

"*EGN2020C gave me an introduction to basic modeling and programming which was so, so useful for me during Spring Career Showcase - I was actually able to secure an internship as a sophomore and would attribute it partly to having been able to develop these skills so early on! Not only that, but I continued to develop these skills during my internship and went on to take EGN2020C as well, during which I had a bit of an advantage having already been exposed to some CAD in EGN2020C. In upper division classes now, we are getting more exposure to the engineering design process and I still see the usefulness of having taken EGN2020C today, because I still have somewhat of an advantage having already been exposed to and become familiar with the steps of the design process"* Asian, female, Biomedical Engineering.

Contextual competence was a theme that emerged from the sophomore students' responses. Some of these students explained:

"I don't know that the specific skills like arduino or CAD will be as useful, specifically, but the communication skills and learning to think like an engineer will come in handy for the rest of my life and career." White, female, Electrical Engineering

I learned the importance of failure, and how to take steps to turn a failed prototype into a learning opportunity" White, other, Agricultural and Biological Engineering

"This course gave me a creative outlet within the college engineering that I previously didn't know was an option. It enhanced my communication skills in an engineering environment" White, female, Industrial and Systems Engineering.

Freshmen students were distinct by mentioning "adjusting studies" and "use of tools" as justification for their responses. Some of these students described:

"EGN2020C had a great impact on me. First of all, I really enjoyed the class because it was hands-on and team-oriented. I liked being able to work with the arduino kit, 3D printer, power tools, and soldering kit. I had never been exposed to any of them before taking this class. Experience working with these tools will no doubt be useful to me in my pursuit of a career in engineering. I also liked being able to collaborate with my teammates because it allowed me to

get to know my classmates better and improve my knowledge of the course content. Experience working in a team helped me improve my teamwork skills which will be very useful to me as an engineer in any professional environment" White, male, Industrial and Systems Engineering

"Being exposed to the arduino kit allowed me to discover my interest in coding. In fact, I am currently taking a computer programming class and seriously considering switching my major from Industrial and Systems Engineering to Computer Science. Thus, EGN2020C helped me adjust my studies and major to an area of study I am truly interested and passionate about. Finally, EGN2020C made me feel like an actual engineer and that is a valuable experience that I am thankful for" White, female, Industrial and Systems Engineering

The qualitative analysis also helps to provide insight into how the authors of the paper and other first-year design educators can continue to reinforce the skills developed as part of the course, and enable future improvements to first-year experiences. One example skill category that emerged in each class standing category was teamwork skills. Students who participated in this survey after taking the course found skills related to teamwork as useful. The skills developed from working in a team are an important outcome of first-year design experiences. We found that as students reflected on the course with more time removed from taking the course they identified different aspects of teamwork as useful. For example, freshmen included time management, sophomores highlighted the interdisciplinary nature of working in a team, and juniors liked how the team project simulated real-life work experience. The multiple perspectives imply that the team-based component of the course is valuable in multiple aspects, and future improvements could include helping the students in integrating some of these aspects as they work on their projects. Design skills and skills related to solid modeling and programming were also present in each of the class standing categories. The usefulness of skills in these areas--as perceived by the students--supports the intended design and implementation of the course to, not only develop these skills, but to provide an experience that promotes achievement and retention.

Limitations

This study has several limitations that need to be considered when interpreting the results. First, the response rate to the survey was 24%, there could be some response bias because non-responders in survey research can have quite different perceptions from those who participate [19]. Additionally, the use of self-reported data is often associated with social desirability [20]. In our case, the fact that the surveys are anonymous could have helped with this limitation. In addition, many researchers have established that self-report data is a credible means of examining students' perceptions [21].

Conclusions

The present study presented an evaluation of a newly implemented introductory engineering design course. We use the usefulness value component described by Jones [2] in the MUSIC Model of Academic Motivation. This component was found appropriate for the current study because it refers to the extent to which students perceive that the coursework is useful to their goals. The results showed that students' perceptions of the usefulness of the course are very

positive overall. Students largely attributed the usefulness of the course to the practice of teamwork, design, and technical skills specifically solid modeling and basic programming. These results support some of the intended goals of the course and provide information that helps to identify areas for the overall improvement of the course.

Considerable research suggests that when students perceive a course to be useful for their short- or long-term goals, students tend to be more motivated to learn and to persist in a determined domain [2], for example, the engineering domain. This points to the role of introductory engineering courses in the curriculum and is useful information for instructors, researchers, and policy-makers who attempt to improve students' retention rates in engineering. The example presented in this study provides a perspective on how to assess the value of practices in engineering introductory courses and students' perceptions. As instructors and instructional designers, we can strive to modify pedagogical practices as necessary by understanding how students perceive the courses. Students might feel more identified with engineering if they perceive the learning activities are useful to their short- or long-term goals. Thus, it is suggested the inclusion of activities that demonstrate how course content is useful and related to students' interests, career goals, and the "real-world".

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