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Redesigning an Introductory Engineering Course to Address Student Perceptions About Engineering as a Profession and Field of Study

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Redesigning an Introductory Engineering Course to Address Student Perceptions About Engineering as a Profession and Field of Study

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***Abstract* - In the first course of an introductory engineering sequence, students from multiple engineering disciplines and diverse college-preparatory experiences are introduced to professional and technical concepts from various engineering disciplines. The course presented a great breadth of topics through a series of tutorials, laboratory experiments, and lectures. When reflecting and commenting on the course, students expressed frustration with a "lack of accomplishment" and "jumping around"—indicators of low self-efficacy beliefs. Further analysis determined that although many quality standalone exercises existed, a guiding narrative for the course was lacking. Over multiple years, the course was redesigned using a pedagogical approach that incorporated research-based instructional practices with a goal of helping the students grow in their understanding of engineering as a general field of study. The motivating principles behind the redesign involved integrally connecting the presentation and practice of both technical and professional engineering skills, introducing exercises perceived as real-world and relevant, and refocusing the course on skills and principles common to engineers of all disciplines. This paper details a restructured curricular model that was designed to be more easily attuned to contextual and audience-specific needs, address students' perspectives on the relevancy of an engineering education, and improve the consistency of the student experience. Central elements of the evolutionary course redesign and a summary of the knowledge-base that informed them are presented. Measurement of student attitudes for four cohorts are discussed and compared to a cohort from before the redesign. The measurements reflect improved student confidence in selection of major, and improved understanding of the impact that engineers have in larger societal contexts among the cohorts.**

Index Terms – assessing student beliefs, design for student engagement, first-year engineering courses, research-based instructional practices (RBIPs).

INTRODUCTION

In the first-year engineering course sequence at Norwich University, students of civil and environmental (CEE), electrical and computer (ECE), and mechanical (ME) engineering, along with construction management (CM) students are introduced to professional and technical concepts from various disciplines of engineering. These students complete a common, general introductory course that introduces fundamental skills and tools through a series of tutorials, laboratory experiments, and lectures.

Previously, an engineering graphics and "fundamentals" style intro sequence was required of all students and the faculty led the programs through a change to the aforementioned model in 2008. In 2012, the author started his faculty career at Norwich and was immediately tasked with "fixing" this introductory course, which was in its infancy. A survey of the situation revealed that: the course had slowly evolved from its pilot description becoming somewhat divorced from the catalog description, members of the faculty and some student constituencies were not happy with it, and nine student learning outcomes (8 of the 12 ABET Criterion 3 outcomes [1] plus one additional school specific outcome related to leadership) were mapped to it. Typical of outlines from older, introductory texts, the course was structured to present a great breadth of topics. When reflecting and commenting on the course, students expressed frustration with a "lack of accomplishment" and "jumping around"—indicators of low self-efficacy beliefs. Further analysis revealed that although many quality standalone exercises existed, a guiding and shared narrative and purpose for the course was lacking.

Over multiple offerings, the author has worked to change the introductory course design using a pedagogical approach that celebrates and investigates skills and principles that transcend multiple engineering disciplines and develops content that helps students grow in their understanding of engineering as a general subject area or field of study. The resultant design attempts to help students develop a lasting understanding that all engineering involves: *the application of problem solving, design, and other processes based on observation and predictive modeling of behavior grounded in knowledge of the foundational principles from math and science for the betterment of society*. Additionally, guiding principles from Astin's theory of student growth and learning [2], the Partnership for 21st Century Skills Framework [3], and the study of intrinsic motivation [4]-[5] informed the principles that guided the subsequent, evolutionary course redesigns over multiple years.

The following hypotheses are proposed: this evolutionary development has resulted in an offering that is attuned to contextual and audience-specific needs at the institution; the offering addresses students' perspectives on the relevancy of an engineering education; and the modifications resulted in improvements to the consistency of the student experience. The next section of the paper details the first-year engineering experience landscape, including universal and local issues that informed the practices implemented. Following this, key elements of the course redesign are introduced. Subsequently, the results of students' self-assessment of their beliefs with respect to a few key design objectives over multiple class years are discussed. The author hopes that others may find inspiration in the process and results presented as they work to attune their offerings to constituencies at their own institutions.

FIRST-YEAR ENGINEERING EXPERIENCE LANDSCAPE

In attempting to systematically evolve an introductory engineering course for the purpose of better attuning it to the expectations of the faculty, the needs of the local students, societal needs for an educated workforce, and the global dynamics of higher education, understanding past educational innovations and their reported findings is important. Additionally, aligning the proposed initiatives to research-based instructional strategies to maximize impact is beneficial. This section details key findings universally relevant to the first-year experience in areas related to the knowledge and attitudes of students entering the STEM-pipeline, and the use of evidence-based instructional practices (EBIPs) to create authentic opportunities for mastery experiences through the use of student-centered pedagogies. Throughout the discussion of key findings, four related guiding principles are proposed; these principles informed the resultant course redesign. Additionally, the institutional setting for students in the first-year engineering course at Norwich University is detailed.

Universal Educational Contexts

Hirsch et al [6] detail studies that explore negative stereotypes students commonly have of engineering and the correlation between a student's pre-college attitudes towards engineering and his or her success and persistence in an engineering program of study. Subsequently, they present findings [6] that demonstrate that even when students have a positive attitude towards engineering, they typically know little about the profession or "what engineers do." In an attempt to address the preparedness of US students for the future demands of a global workforce and citizenry, the Partnership for 21st Century Skills developed a framework of learning outcomes [3] for US K-12 education. In addition to addressing the classical elements of primary and secondary education knowledge content, the framework aspires to address other skillsets including innovation skills (creativity, critical thinking, communication, and collaboration)—skills typically embodied within engineering practice. *Principle 1) Curricular paradigms that hold professional practices as integral to and inseparable from technical competencies are essential if one wishes to address student perceptions related to "what it takes to be an engineer" and the role for engineers in their careers, communities, and families.*

A report on the constituent elements of effective science instruction [7] presents that regardless of the mode of instruction, learning objectives are best achieved when teachers encourage students to align their thinking to clear goals and relate their thoughts to things from their own life-experience. Not unlike the work of Deci [4] and Daniel Pink [5], the report considers intrinsic and extrinsic motivators, acknowledges the inescapability of extrinsic motivators, and stresses the need for instructional techniques that encourage intrinsic motivation of the student. Deci's motivation theory tells us that one can actively construct experiences in ways that increase the intrinsic motivation of others; this is best accomplished by designing the experiences to create a sense of autonomy, relatedness (connection to something larger than one's self), and competency (progress towards mastery of a skill) among participants [4]. Alexander Astin developed a theory for student growth and learning based on five aspects related to the quality and quantity of student involvement: time and energy studying, time spent on campus, participation in student organizations, interaction with faculty and staff, and interaction with other students [2]. An important implication of the study is the hypothesis that the "effectiveness of any educational policy or practice is directly related to the capacity of that policy or practice to increase student involvement [2]." Many universities have used Astin's work as a basis for designing required "involvement inducing" intervention strategies, and then studied their effectiveness with respect to this hypothesis. *Principle 2) Well-attuned curricular changes incorporate techniques designed to support better intrinsic motivation by students while anchoring the world-experience of the constituents, regardless of how limited, to engineering practice.*

In [8], researchers with Vanderbilt's Cognition and Technology group explore the usefulness of authentic experiences to serve as a "hook or anchor" to incorporate some of the positive attributes of "apprenticeship training in formal educational settings." These techniques are at the foundation of student-centered pedagogies which often result in the blending of content across disciplines in support of incorporating richer, more realistic, design-based educational experiences. Yet, the ability for students to connect their specific educational backgrounds to broader, more authentic topics and recognize the value of multiple perspectives has been identified as a major barrier to cross-disciplinary learning [9]. Furthermore, the complexity of such challenges creates a challenge requiring the constraint of projects such that students with little experience will perceive their performance as successful—as a mastery experience. One's self-perception of content mastery is highly linked to one's self-reported enjoyment, interest, and satisfaction; mastery experiences are key to shaping students' self-efficacy beliefs [10]. *Principle 3) Student-centered exercises that transcend disciplinary boundaries and focus on skills fundamental to all engineering disciplines are essential to achieving the changes described in 1) and 2), but much planning and care is needed to help students connect the exercises to their past experiences and the learning objectives of the course.*

The Higher Education Research Institute conducted a faculty survey [11] and found that the adoption of "student-centered" pedagogies by both male and female faculty teaching in the STEM disciplines is significantly less likely to occur than in all other fields, regardless of the size of the class. Many of the student-centered pedagogies have been identified as techniques that increase student-engagement [12]. A wealth of research-informed practices exist to guide the development of a well-formed, evidence-based, innovative general engineering course. This suggests that research-informed best practices met with resources and a college- or departmental-level culture of change could yield improvements to student engagement. *Principle 4) As many introductory courses deal with a large population of students and involve a team of instructors, critical to the success of any change is the ability to create a culture that accepts and respects change and that allows for the instructors to cycle through research-practice and practice-research experiences.*

In light of the aforementioned discussion, the author feels that there is great value in curricular pedagogies that treat the technical and non-technical aspects of typical first-year engineering content as positively co-dependent (inseparable) while creating authentic educational experiences that intrinsically motivate students to learn, using student-centered pedagogies that connect the activities to experiences common to all students and future citizen engineers. As a practical matter, change of this nature is best accomplished iteratively, in cooperation with an instructional team to promote a culture of experimentation for positive change while also building the self-efficacy beliefs of the faculty. As PK-12 science curricula become more inclusive of engineering topics within these contexts, student perceptions of engineering will mature; it is essential that post-secondary engineering curricula remain agile and resilient to complement and exploit these developments. Starting from this perspective and the stated principles, it is essential that the changes be designed to meet the needs of the specific populations served under the constraints of the organization.

Norwich-Specific Educational Contexts

The mission of the Norwich University College of Professional Schools is "to provide our students with the means, motivation, confidence and empathy to engage the problems of our era and create the industries, systems, processes, machines and structures that are required of our evolving society [13]" Within the college, Norwich's David Crawford School of Engineering emphasizes hands-on learning aimed at solving real-world problems in the spirit of that mission and the innovative, founding principles of the institution—to create an education system that would "…make efficient and useful citizens [14]." The hands-on, experiential education at the heart of the institution's ethos is emphasized with all students during the admissions process, and it resonates with that audience. In surveys conducted during the introductory course, the students expressed a very high expectation for hands-on engineering experiences in both lecture and lab, but, overwhelmingly, they revealed that they consider the use of computer software packages or simulations as neither "hands-on" nor relevant.

As inherited in 2012, the first-year engineering sequence at Norwich University consisted of two courses. The first course consisted of a two-contact-hour lecture with a three-contact-hour lab covering topics from all disciplines of engineering at the institution (CEE, ECE, ME, and CM). The second course in Spring term had a similar structure, but was discipline specific. As a part of the introductory course, the author regularly surveys all students. One survey questioned students about their career plans, reasons for enrolling in college, and reasons for selecting a major in an engineering field. A majority of the students provide answers severely lacking in specificity. They seem to have loose motivations that are not integrally coupled to their engineering or even to their post-secondary educations. Through a different line of inquiry, many of the students communicated an understanding of an engineer as one who builds or creates, but they failed to connect the concepts of planning, modeling, analyzing, or testing to the engineering profession. These notions and misunderstandings were central to the expressed frustration by some students that lab exercises focused on those skills were neither "hands-on" nor "engineering."

Managing student expectations for the course seemed intractable at first. Eventually, the author decided that the best path forward was to redesign the course based on the enumerated design principles. As part of the redesign, engineering professional topics were integrated into technical practices in the lab, and career preparation topics were addressed in the lecture to better manage the student expectations by combatting misconceptions and stereotypes.

From these contexts, the next section discusses the high-level, conceptual changes that began to be incorporated in the Fall 2013 and continued throughout subsequent offerings. Following that discussion, the evolution of student self-perceptions as measured by six survey questions over five offerings (Fall 2012 to 2016) is presented.

RESEARCH-INFORMED CURRICULAR INTERVENTIONS

In its *Framework for K-12 Science Education* [15], a committee of the NRC's Board on Science Education uses this working definition for engineering: "any engagement in a systematic practice of design to achieve solutions to particular human problems." Starting from that definition—one that will have a growing formative influence over future constituents for university-level first-year engineering courses—the author worked to outline a definition that would guide the course and its content. Based on an ever-developing understanding of engineering as a field of study and the hallmarks of engineering practice, the following definition of engineering resulted: *the application of problem solving, design, and other processes based on observation and predictive modeling of behavior grounded in knowledge of the foundational principles from math and science practiced for the betterment of society*. An education that helps students develop a lasting understanding of engineering as defined above while providing opportunities for students to practice skills of appropriate scope necessitates that the students develop communication, collaboration, leadership, and other professional skills as well as the higher order thinking skills related to application, synthesis and evaluation.

Building from this understanding, content changes were introduced, focuses were shifted, and the structure was updated, reshaping much of the existing content and capitalizing on existing resources, guided by the principles listed below:

A. ***Professional skills content should be presented as integral to the practice of engineering and not presented as an ancillary, add-on, or tangential topic.*** All technical topics practiced in lab should incorporate some elements of professional practice, connecting them to the profession and to the communities interested in the topic. This means the content should also be integrated into homework, quizzes, exams, and all categories of content for which grades are assigned.
B. ***Exercises should be modified to connect the technical content items to the common experience of the students to increase the student-perceived relevance of the discipline and to solidify the students' choice of educational pursuits.*** This often requires just-in-time updates to exercises based on current events and the interests and experiences of the students as uncovered by the instructor through a variety of techniques.
C. Presenting a "buffet" of technical content exercises as a sampling for each of the many disciplines should end; ***discipline-specific challenges or exercises should be used as a context or setting for exploring engineering skills (both technical and professional) that are common to the practice of engineering in ALL disciplines.*** This allows for a breadth of disciplines to be presented while enabling focused and scaffolded content exercises that helps the students experience and perceive themselves as building competency.

The above principles guided changes that were made predominantly during the 2013 and 2014 offerings. With those fundamental changes introduced and the focus shifted, changes to the subsequent offerings in 2015 and 2016 focused on operational optimizations and incremental modifications to activities to improve student learning outcomes.

In 2012, a 30 question survey was given to students at the end of the course. The survey focused on student perceptions of engineering as a profession, program of study, and on their perceived mastery of key learning outcomes. Those results serve as a baseline for student perceptions and attitudes following the course, before the research-informed interventions and practices were introduced. Subsequently, 25 of those original 30 survey questions were selected and consistently administered during the final week of classes with students in the 2013 – 2016 class offerings. The students were asked to rate their level of agreement with each survey question / statement using the Likert scale shown in Figure 1.

The list below contains six survey questions pertinent to exploring a change in student perceptions about engineering as a profession and field of study (the full complement of questions probed various attitudes and beliefs). Table I shows the survey question number and the motivation behind its inclusion in the assessment in the context of the guiding principles discussed herein. The progress or evolution of student self-perceptions and attitudes related to each question are presented in the following section.

Q1. As a result of this course, my understanding of the various engineering disciplines improved.
Q9. As a result of this course, my understanding of the non-technical impacts of engineering solutions (global, economic, environmental, etc.) increased.
Q10. As a result of this course, my understanding of the role engineers play in keeping the population safe improved.
Q11. As a result of this course, my desire to improve myself through means outside of the traditional classroom improved.
Q16. As a result of this course, my ability to take initiative and act in a leadership capacity improved.
Q18. I feel that this course increased my confidence in my major selection (regardless of major).

Strongly Disagree	Moderately Disagree	Slightly Disagree	Neutral	Slightly Agree	Moderately Agree	Strongly Agree
1	2	3	4	5	6	7

FIGURE 1
LIKERT SCALE FOR SURVEY RESPONSES.

TABLE I
SURVEY QUESTION CONCORDANCE

Question	Motivating Need
1	Students still build an understanding of the profession and its disciplines, despite the focus on the unifying aspects.
9	Students connect the disciplines and profession to problems of human import and see potential for making an impact.
10	Same as Q9.
11	Students build a sense of agency with respect to their education; students perceive growth / content mastery.
16	Students connect the professional and technical competencies they developed to practice.
18	Students exit with stronger personal commitment to their intended program of study.

STUDENT SURVEY RESULTS

The data presented in this section shows the normalized student responses to the aforementioned survey items for the survey years of 2012 to 2016.

When considering the six questions, it is important to note that although the questions are phrased differently and crafted with different motivations as discussed in Table I, they all relate to the central design objective of increasing the student-perceived relevance of the course content. Informed by the rich engineering education knowledge base, the author hypothesized that movement on this front would translate to increased student intrinsic motivation and an improved commitment to their intended program of study by the course constituents.

Table II contains cumulative data for the percentage of student respondents who responded with a mark of 5 or higher and a mark of 6 or higher to each of the six survey questions for the 2012 through 2016 survey years. Figure 2 includes a plot of the trend data for those responding with a mark of 6 or higher for the six questions. One can see that a "steep" increase occurs for all six questions immediately in 2013, and, in general, the increase seen in 2013 continues to progress more slowly (with some limited downturn-recovery transients), or stabilizes and is maintained

TABLE II
CUMULATIVE SURVEY RESPONSE DATA

Question	Response Value	% Responses by Response Value				
		2012	2013	2014	2015	2016
1	5+	*77.7*	88.8	95.0	85.7	83.8
	6+	*48.8*	70.4	74.2	65.9	60.6
9	5+	*76.0*	79.2	87.4	85.7	76.8
	6+	*37.2*	53.6	57.1	68.3	56.3
10	5+	*78.5*	84.0	88.3	87.3	85.9
	6+	*46.3*	61.6	65.0	65.9	64.1
11	5+	*76.0*	85.6	84.2	81.7	83.8
	6+	*49.6*	60.0	63.3	57.1	59.9
16	5+	*73.6*	82.4	84.9	84.1	78.9
	6+	*41.3*	60.8	60.5	54.0	60.6
18	5+	*67.8*	79.8	83.2	77.0	81.0
	6+	*49.6*	61.3	63.9	62.7	57.0

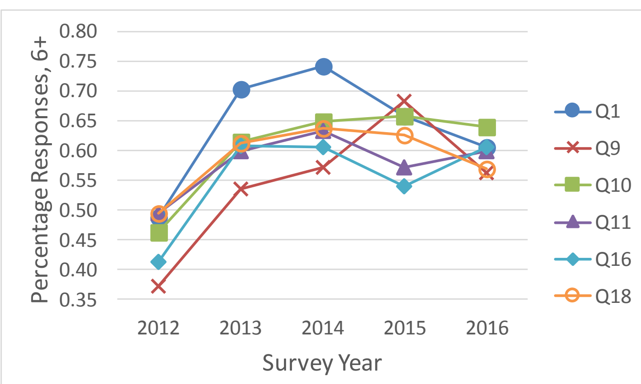

FIGURE 2
ANNUAL RESPONSE RATES OF 6 OR GREATER FOR EACH SURVEY QUESTION.

Figures 3-8 depict the change in student response data over time for each question. While the students were asked to provide discrete responses between 1 and 7 and the interpolated values present in the plots were not possible, looking at the slope of the envelope plot, and how the "mass" of the data shifts is a helpful aid for visualizing the change of the self-perceived student abilities over time.

As one looks at the survey data, consider the 2012 sample set as a baseline reference. Figure 3 shows immediate shifting to the right of the responses, indicating an increase in the level of agreement by the respondents. This increase is sharp in 2013, reaches its peak in 2014, and starts to slowly roll-back in 2015 and 2016. Despite the slight retraction, the responses retain a similar shape that is "stable" and distinctly different from 2012. Figure 4 shows gradual improvement in 2013, with continual subsequent improvement through 2015, and a slight retraction in 2016. Although the number of responses indicating moderate or better agreement is higher, the number of responses indicating general agreement is the same, making this an item for further exploration. Figure 5 represents a sharp increase in 2013 that is maintained and sustained throughout the duration. Figure 6 shows a less sharp improvement in 2013 that remains similar throughout the duration of the survey period. Figures 7 and 8 show sharp initial improvement in 2013 that is sustained throughout the duration of the survey period, but the shapes of the responses in each survey year are dissimilar indicating that there is less stability or continuing development occurring for these items, making this an item for further development and monitoring.

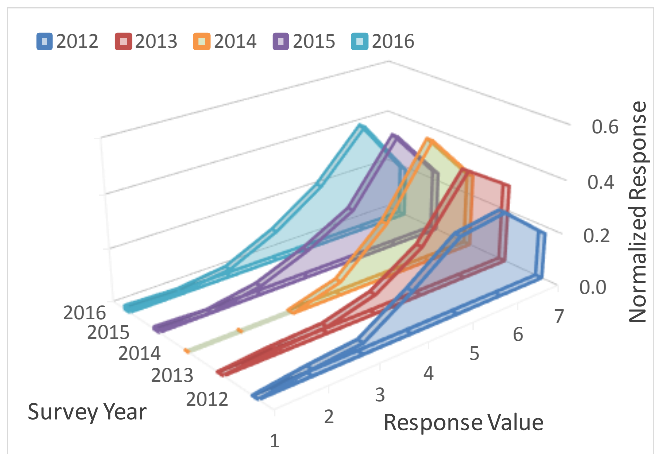

FIGURE 3
SURVEY RESPONSES FOR QUESTION 1.

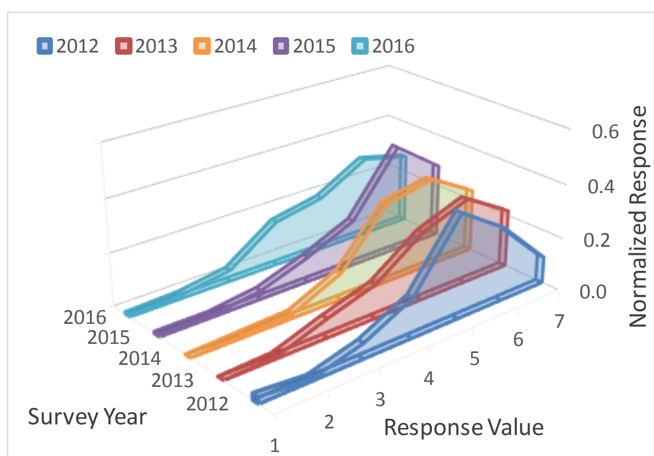

FIGURE 4
SURVEY RESPONSES FOR QUESTION 9.

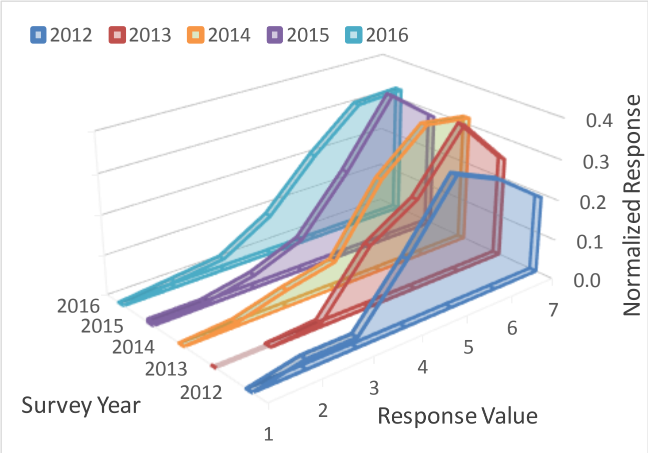

FIGURE 5
SURVEY RESPONSES FOR QUESTION 10.

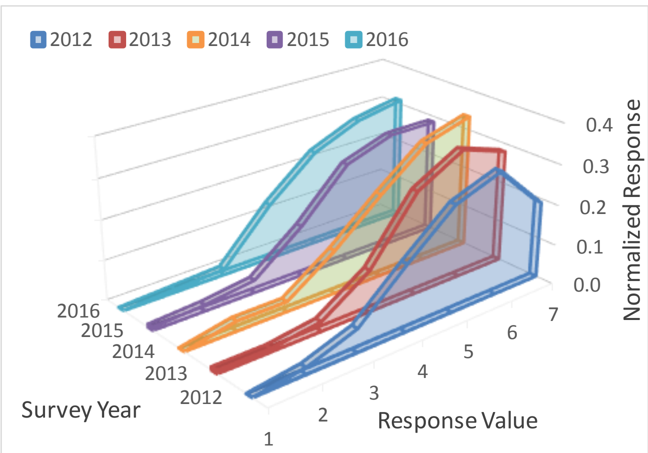

FIGURE 6
SURVEY RESPONSES FOR QUESTION 11.

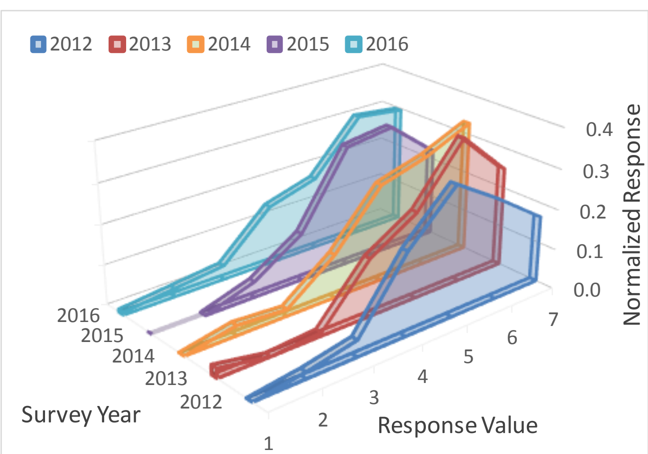

FIGURE 7
SURVEY RESPONSES FOR QUESTION 16.

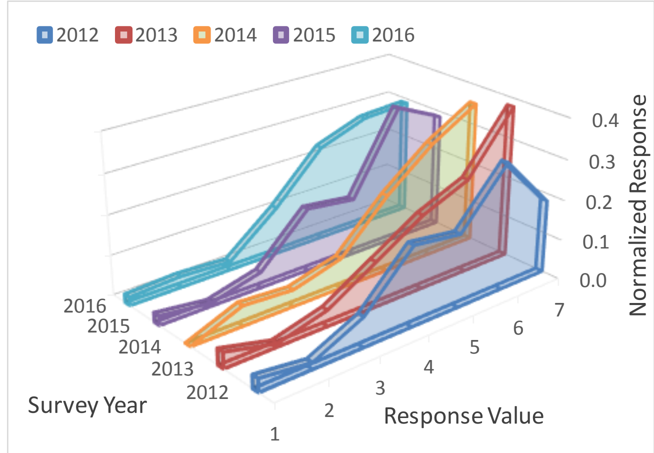

FIGURE 8
SURVEY RESPONSES FOR QUESTION 18.

CONCLUSIONS AND FUTURE WORK

The survey trends presented in this paper are reflective of student self-perceptions and beliefs with respect to the engineering profession and their engineering education. The perception changes among the students as measured by the increased agreement among the respondents in the 2013-2016 cohorts are a result of significant, incremental course redesign over multiple years. The students' attitudes and beliefs related to: confidence in major selection, understanding of the field of engineering and its sub-disciplines, and understanding of the impact engineers have in larger societal contexts improved. The results show the success of the course interventions at effecting change among the local student population.

Progress on the fronts mentioned above is desirable as a body of research relates these items to improved student motivation and increased self-efficacy beliefs. The results presented in this work focus on student responses to six of twenty-five questions. Additional work is needed to analyze the twenty-five question instrument and determine which questions or assessment items are the most influential and representative of underlying student development. Additionally, the construction of a new instrument that can directly assess the impact of key student perceptions as well as one that can measure shifts in individual student perceptions with more granularity is desirable.

The author hopes that the motivations behind the interventions described in this paper and the change in student perceptions that resulted will serve as inspiration for others within this community as they work to improve the first-year engineering experiences on their campuses.

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