COURSE CHOICE OPPORTUNITY AND TECHNICAL—NON-TECHNICAL BALANCE IN UNDERGRADUATE ENGINEERING EDUCATION

by

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Course Choice Opportunity and Technical—Non-Technical Balance in Undergraduate Engineering Education
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If we are to address the enrollment challenges that we face in engineering education, we must consciously adapt to better serve students in concert with their innate psychological needs and properly educate them for increasingly diverse career paths via more flexible degree programs. A conscious cultivation of program environments to meet students' need for autonomy coupled with a purposeful allocation of technical and non-technical degree program content that responsibly educates the engineers of our future are fundamental renovations suggested for undergraduate engineering education.

This thesis lays foundational work for the advancement of engineering education by exploring the course choice opportunities and technical—non-technical coursework balance allocated to undergraduate engineering students in hundreds of diverse engineering degree programs across the United States. *Course choice opportunities* are defined as occasions over the duration of a degree program when a student is given the freedom to choose his or her courses, such as free electives, engineering electives, or humanities electives.

Findings suggest that while comparatively minimal course choice opportunity is prevalent in engineering degree programs, this program model is unnecessary from an accreditation standpoint and incongruent with the psychological needs of students. Exceptional accredited, prestigious, and specialized undergraduate engineering degree programs exist that are far more

autonomy-supportive in terms of providing substantial course choice opportunities to students, demonstrating exciting possibilities for reworking the design of undergraduate engineering degree programs to better support students' psychological needs.

Results also indicate that a wide range of technical—non-technical balance exists across the nation's undergraduate engineering degree programs, which may cause students to find themselves enrolled in engineering programs that do not reflect the curricular experience they expected, nor are well-matched for their career aspirations. Today's engineering graduates go on to diverse career paths, in both what are traditionally categorized as "technical" and "non-technical" fields, requiring a blend of both skillsets in differing proportions. The community of engineering educators should become more informed, intentional, and forward-thinking about these differing curricular allocation opportunities, so that this wide range of technical—non-technical balance can become a conscious asset of differentiated education to better serve society and students.

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CHAPTER 1

INTRODUCTION

The Urgency for Engineering Education Reform

Scientists and engineers make up only 4 percent of the United States' workforce, but play a role in creating jobs for much of the other 96 percent (National Science Board, 2010). Our global economic competitiveness, national security, and standard of living hinges on the consistent production of a technically-skilled and literate workforce and the scientific and technical innovations they produce (Institute of Medicine, NAE, and NAS, 2007, 2010; NAE, 2004, 2005; NAE and NRC, 2009), but short of extreme and consistent Science, Technology, Engineering and Math (STEM) education and workforce interventions, we are on track—and have begun—to fall behind on a global scale (Institute of Medicine, NAE, and NAS, 2007, 2010). One contributing factor to this "gathering storm" (Institute of Medicine, NAE, and NAS, 2007, 2010) is the inadequate enrollment of undergraduate engineering students (NAE, 2005). National leaders have repeatedly attempted to address engineering education access challenges with formal calls for improved K-12 STEM education (Institute of Medicine, NAE, and NAS, 2007, 2010), including widespread adoption of design-based engineering education (NAE, 2005; NAE and NRC 2009), the recently released engineering-infused national science standards (NGSS), and efforts to improve the public perception and understanding of engineering (NAE 2005, 2008).

Despite these efforts and calls to action, today's undergraduate engineering enrollments leave much to be desired. While high school students are increasingly drawn to STEM careers and college majors, female interest is decreasing (myCollegeOptions & STEMconnecter, 2012;

Robelen, E., 2013)—with the gender gap the widest for engineering. Though women make up over half of the college population (National Center for Education Statistics, 2014), they make up less than 20 percent of the undergraduate engineering bachelor's degree recipients (ASEE, 2013), compared to about 40 percent in mathematics and the physical sciences and 60 percent in the biological sciences (National Center for Education Statistics, 2013). Numerous studies indicate that in most engineering disciplines there is no differential attrition by gender (Costentino de Cohen and Deterding, 2009; Hartman and Hartman, 2006; Lord et al., 2008; Ohland et al., 2008; Seymour and Hewitt, 1997), and that the large gender disparities among graduates are due to the low initial enrollment of women in engineering, rather than poor differential retention (Costentino de Cohen and Deterding, 2009). In fact, previous findings suggest that retention of women in engineering is no worse than other disciplines; rather, engineering differs from other majors most notably by "a dearth of female students and a low rate of migration into the major" (Ohland et al., 2008).

If we are to turn these tides, we will need to attract more women and men *to*—and retain them *in*—engineering. This immense undertaking will require an overhaul of engineering education, and necessitate a willingness to stretch beyond the nature of many current interventions, such as community-building, cognitive development, or occupation-choice interventions, that work to address these challenges by changing the *students* (Watson and Froyd, 2007), and expand towards a holistic approach of thoughtfully sculpting engineering education as a whole to better support students. We must leave behind the perception of engineering education as a leaky pipeline (Stevens et al., 2008; Watson and Froyd, 2007)—an image that fails to capture the complex nature of access and retention challenges, and implies we can simply plug up the leaks instead of fix the broken system.

Systems-thinking is needed to tackle the complex, interdependent, oftentimes multidisciplinary problems that engineers encounter in the workforce (NAE, 2004), and given the changing professional landscape in which today's engineers work (NAE, 2004, 2005), engineers need "dynamism, agility, resilience, and flexibility" (NAE, 2004). Engineering education must reinvent itself (NAE 2005) for a society best served by a nimble, culturally competent (Chubin, May, and Babco, 2005), and broadly-educated engineer (NAE, 2005), whose education was infused with real world experiences (AMD NextGen Engineer and NAE, 2012) in a diverse setting (Chubin, May, and Babco, 2005; Wult, 1998).

The aim of this thesis is to inform and ignite engineering education reform at the undergraduate level by taking stock of current engineering degree program models and making evidence-based recommendations for improvements to program designs with respect to two main areas: 1) *course choice opportunities* and 2) *technical versus non-technical coursework allocations*. Course choice opportunities are occasions over the course of a degree program when a student is given the freedom to choose his or her course, such as a free elective, engineering elective, or humanities elective. For this research, "technical" was defined as coursework in engineering, natural science, or math, while "non-technical" was defined as coursework outside of engineering, natural science, and math. Both topics will be discussed further throughout this introductory chapter and explored in depth in the coming chapters of this dissertation.

The Power and Necessity of Choice

"Choice is essential to autonomy, which is absolutely fundamental to well-being. Healthy people want and need to direct their own lives." –Barry Schwartz, 2004

At the turn of this century, the Accreditation Board for Engineering and Technology (ABET) moved to outcomes-based accreditation under the Engineering Criteria 2000 (EC 2000), with the goal of both updating required competencies for engineering programs and increasing the flexibility of how programs reach their educational objectives. The National Academy of Engineers recommends that undergraduate engineering programs should introduce interdisciplinary learning and "more vigorously exploit the flexibility inherent in the outcomes-based accreditation approach to experiment with novel approaches for baccalaureate education" (NAE, 2005). The American Society of Mechanical Engineers (ASME) Vision 2030 Task Force named "increased curricular flexibility" as one of seven recommended actions intended to strengthen undergraduate mechanical engineering education (Kirkpatrick, Danielson, and Perry, 2012).

Developmentally, infusing engineering curriculum with choice and flexibility makes sense, considering "most 18 to 24 year olds significantly redefine their self-identity, a process which involves exploring many factors including: gender role identity, racial identity, social group identity, and professional identity" (Watson and Froyd, 2007). And from a psychological perspective, curricular choice and flexibility may be *essential*. Self Determination Theory (SDT), researched since the 1970s, posits that humans have three innate psychological needs: the need for competence, the need for relatedness, and the need for autonomy (Deci et al., 1991; Ryan and Deci, 2000). Autonomy refers to "being self-initiating and self-regulating of one's own actions" (Deci et al., 1991) or "the feeling of volition that can accompany an act" (Ryan and Deci, 2000). Significant SDT research has aimed to find out how environmental factors or "societal-contextual conditions" can encourage or hinder one's ability to meet these psychological needs and "enhance versus undermine intrinsic motivation, self-regulation, and well-being" (Ryan and

Deci, 2000). It has been found that "choice, acknowledgement of feelings, and opportunities for self-direction…enhance intrinsic motivation because they allow people a greater feeling of autonomy" (Ryan and Deci, 2000). Conversely, failure to support the needs for competence, relatedness, and autonomy contributes to alienation and ill-being (Ryan and Deci, 2000), demotivation and impairment of developmental processes (Deci et al., 1991). Put another way, "when people have no choice, life is almost unbearable" (Schwartz, 2004).

But, providing choices for students can be either motivating or demotivating; in order to realize the benefits of choice, it has to be done right (Schwartz, 2004). The psychologically paralyzing effect of an overload of meaningless choice is evident in countless increasingly complex consumer decisions (Schwartz, 2004). However, choice can be motivating in educational settings and can also enhance learning and well-being (Deci et al., 1991; Ryan and Deci, 2000; Vanasupa, Stolk, and Harding, 2010; Vanasupa, Stolk, and Herter, 2009) when "the options are relevant to the students' interests and goals (autonomy supportive), are not too numerous or complex (competence supportive), and are congruent with the values of the students' culture (relatedness supportive)" (Katz and Assor, 2007). Promoting a sense of choice is central to self-determination, which is not only an important developmental goal, but also the "avenue to attaining outcomes such as creativity, cognitive flexibility, self-esteem" (Deci et al., 1991), increased engagement, and higher quality learning (Deci et al., 1991; Ryan and Deci, 2000).

These SDT research findings could hold untapped, important information for undergraduate engineering education reform about the potential to impact engineering students' academic motivation, commitment, and performance by intentionally fostering education environments supportive of their psychological needs. An education environment (such as an

engineering college and/or engineering degree program) looking to reap these benefits must be "autonomy supportive," making it possible for students to satisfy their innate psychological need for autonomy by encouraging self-determination and providing choices, as has been demonstrated in various classroom settings (Deci et al., 1991; Jones, 2009; Jones and Wilkins, 2013; Ryan and Deci, 2000; Vanasupa, Stolk, and Harding, 2010; Vanasupa, Stolk, and Herter, 2009).

By extending the notion of autonomy-supportive educational environments at the undergraduate level beyond classroom learning activities that effectively employ choice, we can begin to evaluate the power of choice to benefit educational outcomes in the summative picture with the overall design of an undergraduate engineering degree program. That is, can meaningful course choice opportunities afforded to engineering students as they matriculate through an autonomy-supportive undergraduate degree program stand to foster the same benefits demonstrated at the classroom level? And, do highly restrictive engineering degree programs that are unaccommodating to students' psychological and developmental need for autonomy hinder broadening participation, program enrollments, retention, and persistence to graduation?

Given that each undergraduate student arrives furnished with innate and undeniable psychological and developmental needs to experience autonomy and make their own choices, it is logical to surmise that this basic human need for autonomy, the desire to feel a sense of volition in one's acts, will inevitably bleed into student desires to experience the opportunity to explore academically over the course of the undergraduate years. Yet, preliminary results suggest that, by-and-large, engineering students are afforded minimal opportunities to explore academically through choosing their courses. Results of a five-university pilot study quantifying course choice opportunities demonstrated significant course choice opportunity *disparities* between

engineering and non-engineering students, with engineering students—across the board—getting less course choice opportunity (Forbes, Bielefeldt, and Sullivan, 2015).

These results are explicable, considering the seemingly impossible order for undergraduate engineering programs to prepare well-rounded graduates with the necessary knowledge, skills, and competencies for a professional degree amidst longstanding pressures to decrease total credit hours over the same 4-year period (Bucknam, 1998; Russell, Stouffer, and Walesh, 2000). Faced with fewer credit hours and the need to impart a complex, evolving skillset to engineering students, flexibility in these degree programs has long since been diminished, with free electives commonly eliminated (Epstein, 1991).

Less predictable, however, is the psychological effect of this course choice disparity on engineering students, though it is hypothesized (based on SDT) that there is, in fact, a psychological effect and that the effect is injurious to engineering students. This hypothesis ultimately infers that a lack of course choice opportunity in engineering programs could be a possible contributor to the enrollment and in-migration challenges facing undergraduate engineering education in the United States. It is also reasonable to hypothesize that systemic changes to undergraduate engineering education beyond the classroom—such as integrating more curricular choice opportunities and self-direction into the overall design of a degree program—are likely to have similar beneficial outcomes to those demonstrated in classroom settings and could ultimately stand to improve enrollment and retention outcomes.

In preliminary findings, students said they want more choice and flexibility in their undergraduate engineering program: in November, 2012, 24% of the University of Colorado, Boulder undergraduate engineering students (n=821) responded to a short-answer, Likert-scale survey, wherein 48% of survey respondents (n=391) “agreed” or “strongly agreed” that they

would "like the flexibility to customize [their] engineering degree program through an individualized, negotiated curriculum," including 46% of male (n=261) student respondents, and a higher percentage, 53%, of female (n=121) student respondents (note: nine of the 391 student respondents chose not to identify as male or female). Results of a Pearson Chi Squared test on these findings revealed a statistically significant difference at the α=0.10 level (p=0.071). When looking specifically at students who "strongly agreed" to wanting a flexible, customizable engineering program, the Pearson Chi Squared test between male and female respondents revealed a p=0.001, with female students finding such a program more desirous than male students.

Before soliciting qualitative data to better understand these student perceptions and answering the critical questions about the impact of course choice opportunity on engineering enrollments and retention, we must first gain a deeper understanding of the state of course choice opportunity across undergraduate engineering degree programs nationwide, and how the opportunities afforded to engineering students compare to those of their non-engineering peers on campus. These topics are explored in Chapters 2 and 3, with an emphasis on highlighting exceptional schools that are finding ways to provide engineering students with greater course choice opportunities within ABET-accredited and specialized engineering programs.

Technical—Non-Technical Course Balance

The recognition that the work of engineers encompasses the humanities dates back to the 1800's (Rojter, 2004). Today, general agreement exists that engineers need considerable understanding of subject matter traditionally thought of as humanities in order to serve effectively and responsibly as professionals (Hynes and Swenson 2013; NAE 2004, 2005; Rojter,

2004; Russell, Stouffer, and Walesh, 2000; Sharma, 2013; Sherk, 2007; Sjursen, 2007). After all, "technical problems frequently are also social, ethical, political, and international problems," (Shert, 2007) and the nature of solutions to these complex problems and the technological design and development they entail are inescapably rooted in *values* often with philosophical and spiritual underpinnings (Luegenbiehl and Dekker 1987).

Humanities and social sciences courses within engineering programs (commonly referred to as "general education") need to be flexible yet coherent (Blewett, 1993), emblematic of engineering as a diverse profession that requires diverse skillsets (Sharma, 2013). Engineers need both the divergent thinking skills (highly developed in humanities students) in addition to the convergent thinking skills traditionally more developed in engineering students (Hudson, 1975). However, engineering education faces pressures to add both technical and non-technical content, amidst rapidly changing technologies and the "growing requirement for engineers to be able to make responsible, cultural, political and social decisions that shape the future of the world" (Sjursen, 2007), while simultaneously facing the aforementioned pressures to decrease total credit hours (Bucknam, 1998; Russell, Stouffer, and Walesh, 2000).

ABET requires that today's accredited undergraduate engineering programs meet a general criteria that, among other requirements, includes (out of a four-year degree): one year of college-level math and basic sciences, one and one-half years of engineering, and a "general education component that complements the technical content of the curriculum and is consistent with the program and institution objectives" (ABET, 2015). This criteria represents a change from the previous requirements which specified a minimum of one-half year of humanities and social science. While ABET's outcomes-based criteria facilitates flexibility for programs to engage diverse approaches in meeting all criteria, there is especially great room for interpretation

of the general education component. But despite the possibilities provided by this outcomes-based approach and the numerous above-mentioned recommendations by our nation's engineering education leaders to the contrary, the predominant focus on technical content knowledge has historically been pervasive in engineering education, and students with broader non-technical interests often get filtered out (Vanasupa, Stolk, and Herter, 2009) or likely never consider engineering in the first place.

As part of a reflective essay assignment for an introductory 1000-level environmental engineering course at the University of Colorado Boulder, some students who decided to leave engineering cited dissatisfaction with the curriculum—including the lack of non-technical courses and course choice opportunities—as a key contributing factor. In the words of one male student, "the [environmental engineering] curriculum is so restricted and narrow that it leaves one little time to explore any other intellectual ambitions in college," and "the limitations of the engineering curriculum were a strong discouragement to me, as I don't see much freedom for engineers to pursue many other academic interests in college if they plan to graduate within four years." This student ultimately decided to leave engineering to pursue a double major in Environmental Studies and Ecology and Evolutionary Biology in the College of Arts and Sciences.

In the words of another male student who left environmental engineering for an Environmental Studies major, "it is beneficial to refresh your mind occasionally with a different type of thinking, and there's no reason the engineering syllabus has to be so unforgiving." Looking at in-migration to engineering, a female student who was enrolled in the journalism school said, "I was hoping that if I were to transfer into the engineering school, I could keep journalism as a second major. However, after studying my four-year course plan, I realized it

would be nearly impossible to do both and still graduate on time. Moreover, I was really hoping I could go abroad at some point during my college career, but with the strict requirements of [engineering] I came to the conclusion that studying abroad for credit would be a difficult thing to do." She ultimately decided not to pursue engineering.

Another first-year student stated, "maybe I've just had the wrong idea about college in general, but I was hoping this would be the place I could finally branch out and enroll in classes that I find necessary and interesting rather than conform to school requirements for graduation. Instead I've only been met with more limitations on what I'm supposed to learn. The idea is frustrating to me because my favorite class this semester is biological psychology and I'd really like to pursue the subject in more depth, but I'm finding that the workload for environmental engineering won't allow me to do so comfortably."

The stories of these four students are not unique; engineering is rarely accused of overwhelming students with choice, or allowing them to tailor their education to match their vision for their future.

Chapter 4 explores these issues through a quantitative lens, examining the current state of technical versus non-technical coursework balance for a large and diverse sampling of undergraduate engineering programs from across the country. With the year 2020 fast approaching, this study serves as a touch point for capturing how specialized engineering degree programs are distributing required coursework between technical and non-technical areas of study to educate engineers. Specific program improvement recommendations are also outlined in Chapter 4.

Reworking Engineering Education: A Call to Action

Current models of engineering education are "losing the battle for the imaginations of young people," and seeped in a "seemingly endless drudgery of courses that appear to be largely disconnected, not only from [student] interests, but also from the broader picture of what engineering could be, and should be, about" (Kalonji, 2005). In this outcomes-based era, ABET has given engineering educators the power to internally take on the changes called for by national leaders internally rather than to force it externally.

If we are to meaningfully engage this challenge and improve engineering education, we will need to apply the very principles of the engineering design process to undergraduate engineering education itself—iterating the design until it is optimized to attract and educate more engineers effectively and in concert with personal fulfillment. This process demands thinking critically and creatively about undergraduate engineering degree programs from the perspective of the *students*—those currently enrolled and those we hope to attract in the future. This thesis is presented in the hopes of contributing to a student-focused and holistic engineering education renaissance with large-scale findings and tangible recommendations for advancement.

Research Questions

This study begins in Chapter 2 with an exploration of the course choice opportunities afforded to undergraduate engineering students nationwide and how those opportunities compare to those afforded to non-engineering peers on campus. Specifically, the following research questions are addressed:

- What is the extent of course choice opportunities afforded to undergraduate engineering students at the nation's top-ranked engineering schools?

- How do the course choices afforded to engineering students compare to those afforded to their non-engineering peers on campus?
- What is the extent to which course choice opportunity disparities exist between undergraduate engineering and non-engineering students at campuses nationwide?
- And, if overall disparities exist, indicating that undergraduate engineering degree programs provide comparatively less autonomy support in terms of course choice opportunity, do exceptional programs exist that demonstrate the possibility of being both a top-ranked engineering school with ABET Engineering Accreditation Commission (EAC)-accredited engineering degree programs that also give students a comparatively greater freedom to choose courses? Or, rather, are ABET-accredited engineering programs at highly-ranked schools and autonomy-supportive degree programs with respect to course choice opportunity incompatible?

In Chapter 3, the study of course choice opportunity is further delineated within four engineering specialties (chemical, civil, electrical, and mechanical engineering) with an emphasis on identifying exceptional programs that exemplify an autonomy-supportive culture in terms of course choice opportunity. The following research questions are addressed:

- What is the extent of course choice opportunities afforded to undergraduate engineering students enrolled in the nation's top-ranked chemical, civil, electrical, and mechanical engineering degree programs?
- Do top-ranked undergraduate degree programs exist within chemical, civil, electrical, and/or mechanical engineering that do offer substantial course choice opportunities to students?
- How do the course choices afforded to chemical, civil, electrical, and mechanical engineering students within the same engineering college compare to one another?
- Nationally, are certain engineering disciplines more inclined to be autonomy-supportive in terms of affording comparatively more course choice opportunities to students?

Chapter 4 explores the allocation of technical versus non-technical coursework across undergraduate engineering degree programs nationwide. This chapter addresses the following research questions:

- What is the extent of *technical* coursework required of undergraduate engineering students enrolled in the nation's top-ranked chemical, civil, electrical, and mechanical engineering degree programs?
- How do the technical coursework requirements in these undergraduate engineering degree programs compare to those in math and natural science degree programs?
- What is the extent of *non-technical* coursework required of undergraduate engineering students enrolled in the nation's top-ranked chemical, civil, electrical, and mechanical engineering degree programs? Do elective opportunities exist for students to take additional non-technical courses should they so choose?
- Based on the studied population, does consensus exist regarding the appropriate balance of courses between technical and non-technical areas to effectively educate a specialized engineer at the undergraduate level?

Chapter 5 explores whether engineering colleges and degree programs with comparatively more course choice opportunity may be more appealing to female undergraduate students. Specifically, the following research questions are addressed:

- Do engineering colleges that offer their students comparatively more course choice opportunity award a differentially higher percentage of engineering bachelor's degrees to women as compared to engineering colleges that offer less course choice opportunity?
- Do specialized engineering degree programs affording students with comparatively more course choice opportunity have differentially high percentage female enrollments as compared to specialized engineering degree programs that provide their students with less course choice opportunity?

The dissertation closes in Chapter 6 with conclusions and a discussion of future work.

Research Hypotheses

It is hypothesized that undergraduate engineering students are afforded minimal course choice opportunities and that it is common for a substantial disparity to exist between the opportunities that engineering students are afforded to choose their courses and those opportunities afforded to their non-engineering peers on campus. If this hypothesis proves to be supported by the data, the combined effect of minimal course choice *opportunities* for engineering students and large course choice opportunity *disparities* between engineering students and their peers could have detrimental psychological impacts on engineering students, and may be a contributor to the enrollment and in-migration challenges plaguing undergraduate engineering education, including the pervasive inadequate enrollment of female students in many engineering disciplines. The motivation to answer these questions is the critical hypothesis that increasing course choice opportunities for students seeking an engineering degree could be an opportunity to benefit educational and program outcomes by encouraging students to meet their innate psychological need for autonomy within the context of an engineering education.

Despite the opportunities presented by outcomes-based accreditation and recommendations to the contrary, it is hypothesized that the predominant focus on technical content knowledge—at the expense of non-technical content knowledge—may still be widespread in engineering education. It is believed that many engineering programs allocate inadequate portions of coursework to "non-technical" subject matters and that educating engineering students with minimal non-technical coursework is personally egregious and professionally poorly matched to many career paths today's engineering graduates will pursue.

CHAPTER 2

COURSE CHOICE OPPORTUNITY IN UNDERGRADUATE ENGINEERING EDUCATION: NATIONAL TRENDS AND AUTONOMY-SUPPORTIVE EXCEPTIONS

Abstract

This study explores the *course choice opportunities* (such as free electives, technical electives, and humanities electives) afforded to undergraduate engineering students nationwide versus their non-engineering peers on campus. A total of 553 degree programs across 46 top-ranked engineering schools were studied, including 309 Engineering Accreditation Commission ABET-accredited engineering degree programs and 244 non-engineering (mathematics, physics, chemistry, economics, and psychology) degree programs. Findings suggest a national trend of significant course choice opportunity *disparity* between engineering and non-engineering students, with engineering students experiencing far less course choice opportunity. For a normalized 130 credit hour degree program, non-engineering students in the studied programs experience the freedom to choose a median of 24% (~10, three credit-hour courses) of their degree program as free electives, versus a median of a mere 3% (~1, three or four credit-hour course) for engineering students. And, non-engineering students choose a median of 74% of their total degree courses, versus 40% for engineering students. Results also indicate that this finding of highly-restrictive engineering degree program design is unnecessary: exceptional accredited and prestigious undergraduate engineering degree programs exist that are autonomy-supportive, providing substantial course choice opportunities to students. Course choice opportunity data for ten *High Choice Exception* engineering schools with exemplary course choice offerings are presented. Engineering students at these exceptional universities both experience the freedom to choose more of their courses and have less course choice disparity with their non-engineering

peers on campus. In short, choice with quality is possible, if seldom pursued by engineering colleges.

Background

Self Determination Theory (SDT) identifies *autonomy*, the "feeling of volition that can accompany any act" (Ryan and Deci, 2000), as a fundamental psychological need for all humans (Deci et al, 1991; Ryan and Deci, 2000)—including undergraduate engineering students. Classroom settings can nurture and encourage students' intrinsic need for autonomy through the strategic use of freedom, by providing students with opportunities to make choices (Deci et al, 1991; Jones, 2009; Jones and Wilkins, 2013; Ryan and Deci, 2000; Vanasupa, Solk, and Harding, 2010; Vanasupa, Stolk, and Herter, 2009). The choices must be offered mindfully, in harmony with students' other psychological needs for competence and relatedness (Katz and Assor, 2007), and if done right (Schwartz, 2004), the benefits are real, including greater student self-motivation, increased engagement, higher-quality learning, and personal well-being (Deci et al, 1991; Katz and Assor, 2007; Ryan and Deci, 2000).

By extending the notion of autonomy-supportive educational environments at the undergraduate level beyond classroom learning activities that effectively employ choice, we can begin to evaluate the power of choice to benefit educational outcomes in the summative picture with the overall design of an undergraduate engineering degree program. That is, can meaningful course choice opportunities afforded to engineering students as they matriculate through an autonomy-supportive undergraduate degree program stand to foster the same benefits demonstrated at the classroom level? And, do highly restrictive engineering degree programs that are unaccommodating to students' psychological and developmental (Alpay, 2013; Watson and

Froyd, 2007) need for autonomy hinder broadening participation, program enrollments, retention, and persistence to graduation? Before we can answer these questions, we must first gain an understanding of the state of course choice opportunity across undergraduate engineering degree programs nationwide, and how the opportunities afforded to engineering students compare to those of their non-engineering peers on campus.

A preliminary five-university pilot study quantifying course choice opportunities demonstrated significant course choice opportunity disparities between engineering and non-engineering students, with engineering students—across the board—receiving less course choice opportunity (Forbes, Bielefeldt, and Sullivan, 2015). The psychological effect of this course choice *disparity* on engineering students is unknown, but could be a possible contributor to the enrollment, retention, and in-migration challenges facing undergraduate engineering education in the United States. More work is needed to understand the current state of course choice opportunity across the nation, and to determine whether respected undergraduate engineering programs exist that are finding ways to facilitate meaningful course choice opportunities for students without sacrificing program effectiveness, quality, and reputation.

Research Questions

This study builds upon the preliminary five-university study (Forbes, Bielefeldt, and Sullivan, 2015) by asking:

- What is the extent of course choice opportunities afforded to undergraduate engineering students at the nation's top-ranked engineering schools?
- How do the course choices afforded to engineering students compare to those afforded to non-engineering students on campus?

- What is the extent to which course choice opportunity disparities exist between undergraduate engineering and non-engineering students at campuses nationwide?
- And, if overall disparities exist, indicating that undergraduate engineering degree programs provide comparatively less autonomy support in terms of course choice opportunity, do exceptional programs exist that demonstrate the possibility of being both a top-ranked engineering school with Accreditation Board for Engineering and Technology (ABET) Engineering Accreditation Commission (EAC)-accredited engineering degree programs that also afford students a comparatively greater freedom to choose courses? Or, rather, are ABET-accredited engineering programs at highly-ranked schools and autonomy-supportive degree programs with respect to course choice opportunity incompatible?

Methods

With the goal of understanding and capturing the magnitude and frequency of course choice opportunities afforded to engineering students versus their non-engineering peers on campus, a large quantitative study was conducted, spanning 46 top-ranked diverse engineering schools nationwide. The chosen universities encompass the 2013 US News & World Report's top-ranked 22 engineering schools where doctoral programs are offered and the top-ranked 24 engineering schools where doctoral programs are not offered. These engineering rankings are based solely on peer assessment surveys (US News & World Report, 2013). The top-ranked military academies were excluded from this study because of their supplementary educational objectives that stand to influence degree program design and are thus outside the focus of this paper. The general characteristics of the institutions included in the study are summarized in Tables 2.1 and 2.2.

Table 2.1: Full time undergraduate population and 6-year graduation rate data for 46 top-ranked engineering schools (US News & World Report, 2013).

	Total Undergraduate Population (rounded to nearest 1000)	% Undergraduate Population that is ENG	% Total Undergraduate Population that is Female	University 6-year Graduation Rate (%)
Median	6,000	21.7	49.0	85.0
Average	13,000	29.1	46.4	81.9
Minimum	0 (under 500)	2.9	17.0	46.0
Maximum	77,000	96.6	100.0	97.0

Table 2.2: Carnegie Classifications, Carnegie groupings, and full time undergraduate data for 46 top-ranked engineering schools (US News & World Report, 2013).

Carnegie Classification			N	Full Time U-grad Pop. (rounded to nearest 1000)	N	% Full Time U-grad Pop. that is ENG	N
Carnegie Groupings	Baccalaureate	Bac/Diverse (Baccalaureate College—Diverse Fields)	3	0 – 1,000	4	0 – 10	6
		Bac/A&S (Baccalaureate College—Arts and Sciences)	5	2,000	7	11 – 20	16
	Masters	Master's S (Master's Univ.; smaller program)	1	3,000 – 5,000	8	21 – 30	9
		Master's M (Master's Univ.; medium program)	2	6,000 – 10,000	10	31 – 40	4
		Master's L (Master's Univ.; large program)	10	11,000 – 20,000	5	41 – 50	4
	Research Universities	RU/VH (Research University; very high research activity)	21	21,000 – 30,000	8	51 – 60	2
	Not Included in ENG/Non Comparisons	RU/H (Research University; high research activity)	1	31,000 – 40,000	2	61 – 75	2
		DRU (Doctoral/Research University)	1	41,000 – 50,000	1	76 – 90	1
		Spec/Engg (Special Focus Institutions—Schools of Engineering)	2	50,000+	1	91 – 100	2

Course choice opportunities for engineering degree programs accredited by ABET's EAC at each of the 46 universities were analyzed using the university 2013-2014 online course catalog. Twenty-three of the 46 universities also offer non-accredited engineering degree programs that

were not included in this study. Because universities have varying credit hour metrics, in all cases, degree program data collected was normalized to 130 total degree credit hours by multiplying the university course choice opportunity credit hour(s) by 130, divided by the raw university total degree credit hours. This approach accounts for differences in how institutions count credits, including for quarters versus semesters. For example, 2 credit hours in a 32 credit hour degree program would be normalized to 8.1 credit hours (2 * (130 / 32) = 8.1). Normalization to 130 total degree credit hours was chosen based on the average total degree credit hour requirement across all degree programs included in the study. However, there was a statistically significant (Mann-Whitney U two-tailed p = 0.000) disparity noted in the total credits required for accredited engineering ($\tilde{x}$ = 129) versus non-engineering ($\tilde{x}$ = 120) degrees.

To provide a comparison between the undergraduate engineering and non-engineering degree program course choice opportunities that students experience *within* each respective campus, five non-engineering degree program types were also analyzed for each institution: Bachelors of Science and/or Bachelors of Arts degree programs in mathematics, physics, chemistry, economics, and psychology. Selection of these non-engineering degree programs for inclusion in this study is a continuation of the methods developed for the five-university preliminary course choice opportunity study and was

> "informed by the University of Colorado Boulder's 20-year historical trends of the degrees students earn when they leave the College of Engineering and Applied Science (CEAS), but continue on to earn university degrees. The top majors of those students who earn degrees outside of the CEAS, who were in the college at some time are: 1. economics, 2. finance, 3. psychology, 4. integrative physiology, 5. biochemistry, and 6. math. Of those, economics and psychology were chosen for the study because they are degree programs commonly offered at other institutions. Mathematics, physics, and chemistry were also included in the study to gain an

> understanding of curricular choice opportunity in non-engineering Science, Technology, Engineering and Math (STEM) disciplines" (Forbes, Bielefeldt, and Sullivan, 2015).

In the current study, 553 degree programs across the 46 institutions were analyzed, comprised of 309 EAC ABET-accredited engineering degree programs and 244 non-engineering degree programs. Of the 46 institutions studied, five technically-focused universities offered none of the five non-engineering degree programs, and therefore choice opportunity disparities are not presented for these schools. Of the 41 remaining universities, 34 universities offered all five of the non-engineering comparator degrees: chemistry, economics, math, physics, and psychology. Five of the 41 universities offered four out of five of the non-engineering degree programs; one offered three of the non-engineering degree programs; and, one offered only two of the non-engineering degree programs. For these seven schools, all choice variable calculations are based on the university-offered non-engineering degree programs included in the study. Some universities offered both B.A. and B.S. degrees in the same non-engineering discipline(s), and in these cases, course choice opportunity data for both degree programs are included in the non-engineering summary data. It is worth noting that, of the 41 institutions that offered both engineering and non-engineering degrees that were included in this study, 71% required a higher number of total credit hours from engineering programs.

Choice Variables

Four choice variables were developed for this study, collectively affording a multifaceted quantitative delineation of the course choice opportunities undergraduate students experience as they matriculate through various degree programs: Total Free Elective Credit Hours, Total Choice Count, Weighted Choice Score, and Average Choice per Opportunity.

Total Free Elective Credit Hours ("free electives")

Total Free Elective Credit Hours is the sum of credit hours in a given degree program for which there are no restrictions placed on the students' course selection(s)—students are free to pick any course(s) of their choosing. As outlined above, free electives and all choice variable calculations were normalized based on 130 total degree credit hours.

Total Choice Count ("total choice")

Total Choice Count is the total credit hour frequency count of all course choice opportunities for a given degree program (see example in Table 2.4), capturing the *total number of opportunities* (in normalized credit hours) students are allotted to choose their courses. Examples of degree program course choice opportunities include free electives, technical electives, humanities electives, and the opportunity to choose from a menu or list of courses.

Weighted Choice Score ("weighted choice")

Weighted Choice Score is calculated from a weighted matrix of categorized course choice opportunities, and is designed to capture the overall *magnitude of course choice opportunity* in a degree program.

The types of course choice opportunities students could encounter within a given degree program were grouped into four categories (Table 2.3). Weighted Choice Score is the sum of the respective weighted frequency counts from the four course choice categories for a given degree program (again, in normalized credit hours).

Table 2.3. Weighted Choice Score course choice opportunity categories.

Category	Definition	Examples	Weight
1	Courses chosen from a list of options.	"Choose 1 of the following 5 courses" "Choose from the following list"	3
2	Courses chosen from within one department *or* within engineering.	"Math elective," "Computer science elective," "Philosophy elective," "Engineering elective"	22
3	Course choices outside of engineering, chosen from more than one department (but not a free elective).	"technical elective," "humanities elective", "humanities and social science elective"	88
4	Free electives.	No restrictions are placed on these course choice opportunities.	1292

Note: "Engineering electives" (category 2) is distinguished from "technical electives" (category 3), which is chosen from engineering, math, or science.

Course choice category *weights* were determined from the five university pilot-study (Forbes, Bielefeldt, and Sullivan, 2015) that included counting the actual number of courses students got to choose from when allocated course choice opportunities in the various categories. The resulting category weights used for this study (3, 22, 88, and 1292, respectively) represent the overall median values of the number of courses students can choose from for all course choice opportunities across all degree programs studied at each of the five universities included in the pilot study. For example, for all category 1 choice opportunities provided to students across all degree programs at the five universities, students got to pick their course from a median of 3 course options (such as "choose 1 of the following 3 courses")—therefore, the category 1 weight is 3 (Table 2.3). For the actual Weighted Choice Score calculations performed for this 46 university study, the respective category weights were divided by the maximum weight, 1292, resulting in the weighted fractions in the cells labeled **L**, **M**, **N**, and **O** in Table 2.4.

Average Choice per Opportunity

Average Choice per Opportunity is the total choice for a given degree program divided by that same program's weighted choice (Total Choice Count / Weighted Choice Score). This choice variable provides a sense of the *average magnitude of choice* provided by individual course choice opportunities in a degree program.

Table 2.4 shows the weighted choice matrix design, as well as sample calculations for Total Choice Count, Weighted Choice Score, and Average Choice per Opportunity.

Table 2.4. Weighted Choice Score matrix design and example.

Degree	Cat. 1	Cat. 2	Cat. 3	Cat. 4	Total Choice Count **G**	Weighted Choice Score **H**	Average Choice per Opp. **I**
	3 **A**	22 **B**	88 **C**	1292 **D**			
	Weighted Fractions / 1292						
	.0023 **L**	.0170 **M**	.0681 **N**	1 **O**			
Civil Eng. Example	6 **Q**	9 **R**	15 **S**	3 **T**	33 **X**	4.189 **Y**	0.127 **Z**

Note: The bold letters are cell identifiers only.

- Cells **A→D** contain the median values from the pilot study that comprise the basis for the matrix weighting.
- Cells **L→O** contain the actual weights used in the matrix, fractions calculated by individually dividing **A→D** by D.
- Cells **Q→T** contain frequency counts (in credit hours) of the various four course choice categories. In this example, the Civil Engineering degree has 6 credit hours of Category 1

choices (**Q**), 9 credit hours of Category 2 choices (**R**), 15 credit hours of Category 3 choices (**S**), and 3 credit hours of Category 4 choices (**T**).

- *Total Choice Count*: **X** = **Q** + **R** + **S** + **T**.
- *Weighted Choice Score*: **Y** = (**Q*****L**) + (**R*****M**) + (**S*****N**) + (**T*****O**).
- *Average Choice per Opportunity*: **Z** = **Y** / **X**.

Data collection and calculations of university choice variable data were conducted using Microsoft Excel 2013. Because the data were based on course and credit hour counts and are ordinal in nature, nonparametric statistical tests were used throughout this study. The pair-wise Wilcoxon Signed Rank test was used to detect statistically significant differences between engineering versus non-engineering choice variable values (since these values are *by university* and therefore represent two dependent groups of ordinal data). Dispersion analyses, comparing the spread of choice variable values for engineering versus non-engineering programs, were conducted by running Wilcoxon Signed Ranks tests on the Absolute Deviation from Median (ADM) scores. Pair-wise Mann-Whitney U tests (for two independent groups) were used to test for statistically significant differences between universities. Kruskal-Wallis nonparametric tests were conducted to test for statistically significant differences between three independent Carnegie Classification grouping populations for each of the four choice variables. Each of these statistical tests were run using a two tailed $\alpha = 0.05$. The nonparametric Spearman Rank Correlation statistical test was used to test for coefficients of association between ordinal-level institution variables and the ordinal-based choice variable data, here using a two tailed $\alpha = 0.01$ to highlight the most significant correlations.

Kruskal-Wallis and Spearman Rank Correlation analyses were conducted using The Statistical Package for the Social Sciences (SPSS) 23. All other statistical analyses were performed using MVPstats.

Results

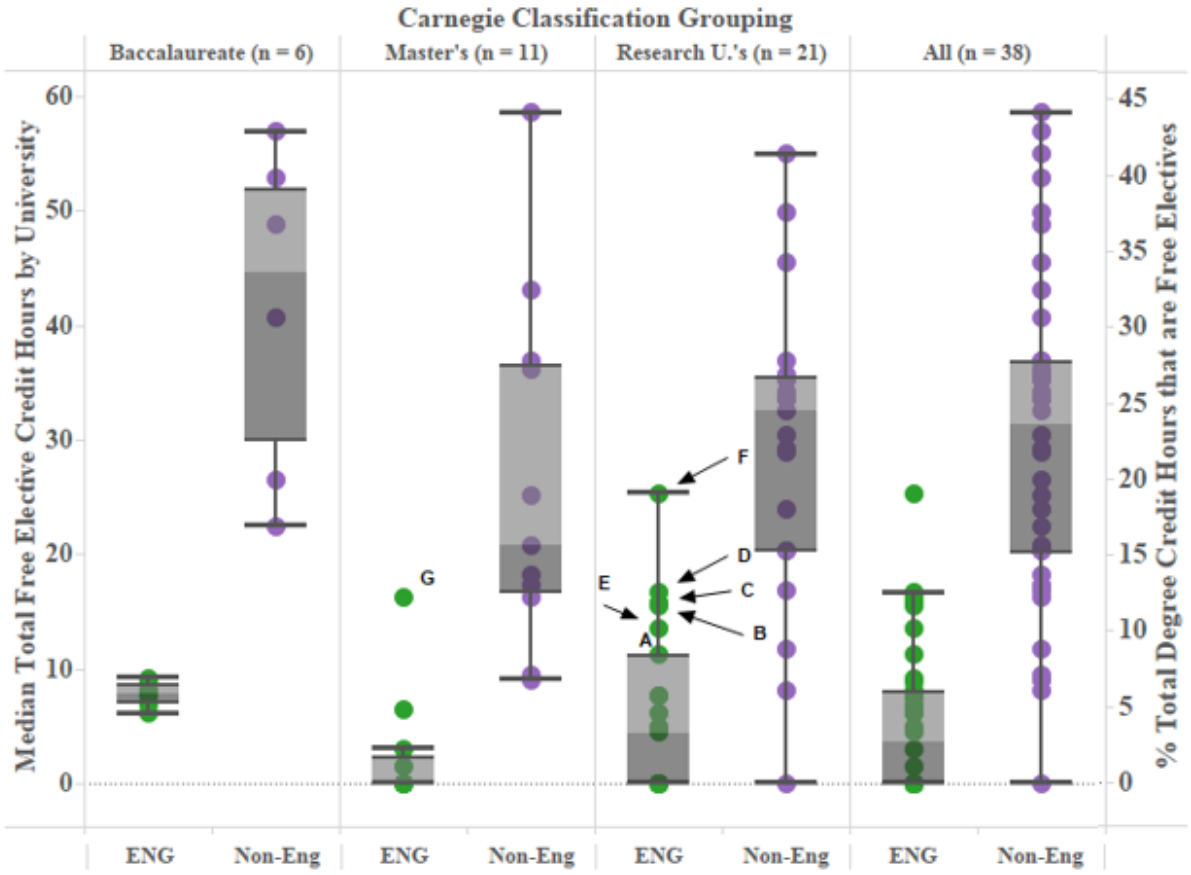
Total Free Elective Credit Hours ("free electives")

Because the course choice opportunity data in this study are based on discrete counts and are ordinal in nature, in all cases median values are reported. Median Total Free Elective Credit Hour values were calculated across all engineering degree programs within each university and across all non-engineering degree programs within each university, respectively. Results of the median free elective calculations by university are presented separated by three aggregated Carnegie Classification (Carnegie, 2015) groupings in Figure 2.1. Each university non-engineering and engineering degree program free elective data points are shown as unique points for the straightforward identification of individual universities. An overlaid box and whisker plot visualizing the minimum, maximum, upper and lower quartile, and median values offers further non-engineering versus engineering comparison across the university range.

Omitted from Figure 2.1 are the "DRU" and "RU/H" (see Table 2.2) university Carnegie Classification categories (due to sample sizes of n = 1, respectively), and the "Spec/Engg" category (one university in this category offered none of the studied non-engineering degree programs, again leaving a sample size of n = 1). Accounting for the four remaining universities that do not offer non-engineering degree programs, median free elective engineering versus non-engineering degree program values are presented for a total of 38 universities. Universities classified (Table 2.2) as "Bacc/Diverse" or "Bacc/A&S" were combined into "Baccalaureate

Colleges" (n = 6). "Master's S," "Master's M," and "Master's L" universities have smaller, medium, and larger, Master's programs, respectively, and were grouped into "Master's Colleges and Universities" (n = 11). The (n = 21) "RU/VH" universities remained grouped as "Research Universities; very high research activity." The same Carnegie Classification aggregations were used for the median engineering and median non-engineering degree program graphs for the four choice variables in Figures 2.1 – 2.4. These same 38 universities were included in all engineering versus non-engineering comparative analyses throughout this chapter.

Figure 2.1: Median engineering versus non-engineering Total Free Elective Credit Hours by university across three Carnegie Classification aggregations.



Note: Labels A, B, C, D, E, F, and G identify High Choice Exception university data points. See Table 2.6.

Half (n = 19) of the universities had median engineering Total Free Elective Credit Hour values of zero, indicating that they commonly offer *no* free elective course choice opportunities to their undergraduate engineering students (n = 1 Bacc., n = 8 Master's, n = 10 RU/VH), with a median for engineering degrees across all universities of 4 free elective credit hours, compared to the median across the three Carnegie aggregations for non-engineering degree programs of 31 free elective credit hours. Based on the normalized 130 degree credit hour total, these values represent non-engineering students choosing 24% (~10, three credit-hour courses) of their degree programs as free electives, versus only 3% (1, three or four credit-hour course) for engineering

students—marking a substantial difference in college academic experiences in terms of course choice opportunity.

Of note is the exceptional RU/VH university offering a median of 25 free elective credit hours to their engineering students (not so far from the overall RU/VH non-engineering median of 33 free elective credit hours), followed by the cluster of five RU/VH schools offering medians of 11 to 17 credit hours as free elective choice opportunities to engineering students. Also of note is the Master's university with a median of 16 free elective credit hours for engineering students, just five credit hours shy of the median non-engineering offering of 21 free elective credit hours for the Master's Colleges and Universities category. These schools, though exceptions, are demonstrating the exciting possibility of granting students considerable opportunities for less restricted academic exploration *within* the context of their highly regarded engineering programs.

For the purposes of this study, these universities are categorized as *High Choice Exceptions (HCEs).* HCE is defined as an engineering school whose median choice variable value(s) fall within the top quartile (or above) of median engineering scores *and* fall within or above the non-engineering bottom quartile of median values. Data for all HCEs for each of the course choice variables are presented in Table 2.6 and discussed in a later section of this chapter.

The dispersion analysis found of a statistically significant difference (p=0.000) in the spread of free elective credit hour opportunities for engineering students versus non-engineering students at the 38 universities. Thus, while there was often little variability in free elective opportunities between the different engineering degree programs, the opposite was true for the non-engineering degree types; physics and chemistry generally allowed fewer free electives ($\tilde{x}$

$_{\text{physics}}$ = 20, $\tilde{x}_{\text{chemistry}}$ = 22) than mathematics ($\tilde{x}_{\text{mathematics}}$ = 28) which allowed fewer than economics and psychology ($\tilde{x}_{\text{economics}}$ = 34, $\tilde{x}_{\text{psychology}}$ = 37).

A Kruskal-Wallis test was used to compare the dispersion of free elective credit hour opportunities for the three Carnegie groups of institutions, again using ADM scores; results were indicative of a statistically significant difference between the university categories (p=0.002). Mann-Whitney U post hoc tests revealed no detectable differences between the spread of free elective opportunities for the Baccalaureate Colleges and Master's Colleges and Universities categories (p=0.297), but statistically significant differences at the α=0.01 level *were* detected between each of these categories and the Research Universities. These results suggest that, from university to university, more variation exists in the number of free elective credit hour opportunities afforded to engineering students at Research Universities as compared to Baccalaureate Colleges and Master's Colleges and Universities.

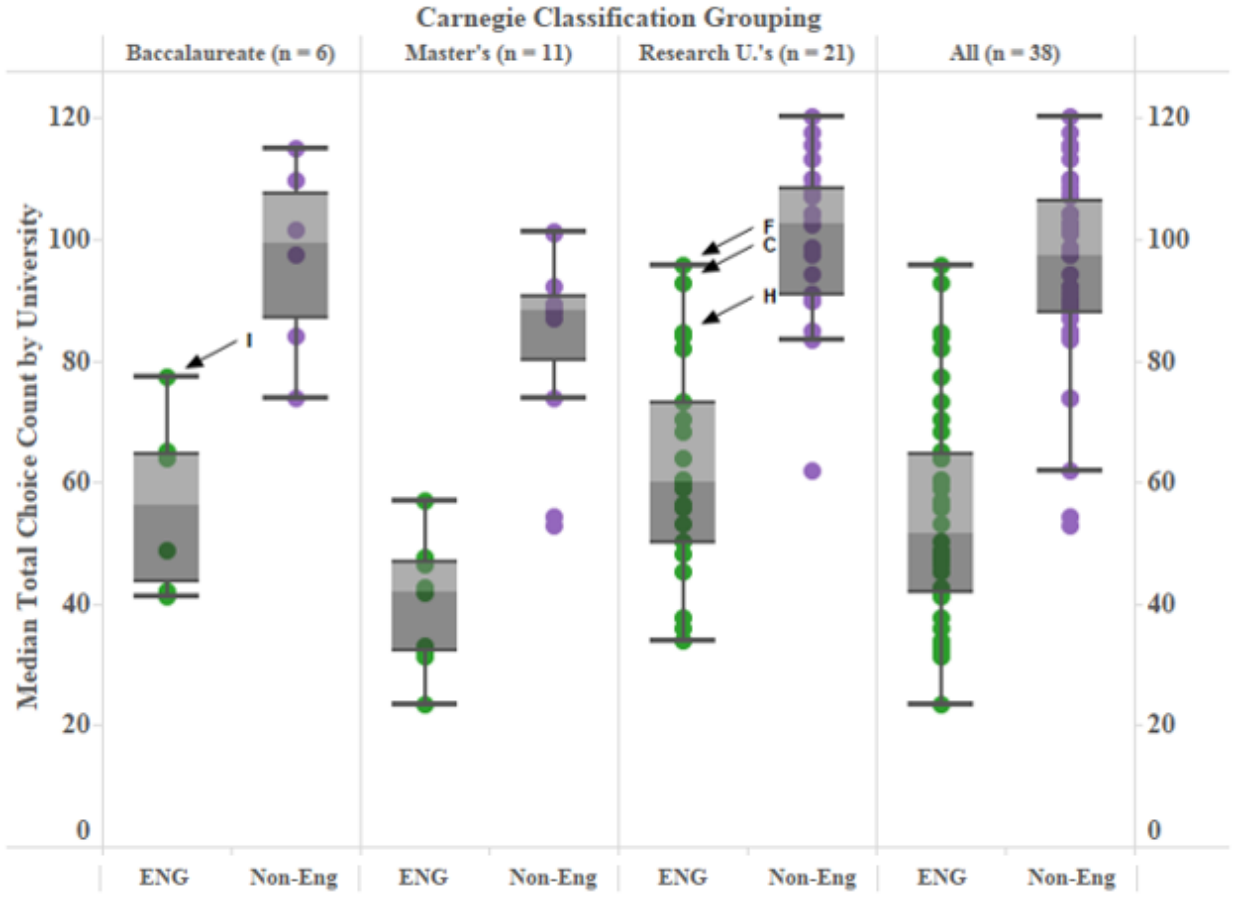
A greater choice opportunity *disparity* (shown as the gap between the clusters of median engineering versus non-engineering Total Free Elective Credit Hour scores) is evident in the Baccalaureate Category, where no exceptional free elective values for engineering approach parity with any non-engineering free elective values.

Course choice value differences *between* engineering disciplines (including chemical, civil, electrical, and mechanical engineering) disciplines will be explored in a subsequent chapter.

Total Choice Count ("total choice")

Representing the frequency count of total course choice opportunities within respective degree programs, Total Choice Count provides a sense of the number of times students are afforded the freedom to choose a course as part of a degree program. As with the free elective calculations above, median total choice values were calculated across all engineering degree programs within each university and across all non-engineering degree programs within each university, respectively. Results of the median total choice values by university are presented within the previously defined three aggregated Carnegie Classification groupings in Figure 2.2.

Figure 2.2: Median engineering versus non-engineering Total Choice Counts by university across three Carnegie Classification aggregations.



Note: Labels C, F, H and I identify High Choice Exception university data points. See Table 2.6.

The median Total Choice Count value for engineering degree programs across all universities was 52 credit hours ($\tilde{x}$ Bacc ENG = 56, $\tilde{x}$ Mast. ENG = 42, $\tilde{x}$ RU/VH ENG = 60), versus 98 credit hours for non-engineering degree programs hours ($\tilde{x}$ Bacc NonENG = 100, $\tilde{x}$ Mast. NonENG = 88, $\tilde{x}$ RU/VH NonENG = 103). There was notable disparity in total choice opportunities across the non-engineering degree types ($\tilde{x}$ chemistry = 78, $\tilde{x}$ physics = 82, $\tilde{x}$ mathematics = 99, $\tilde{x}$ economics = 104, $\tilde{x}$

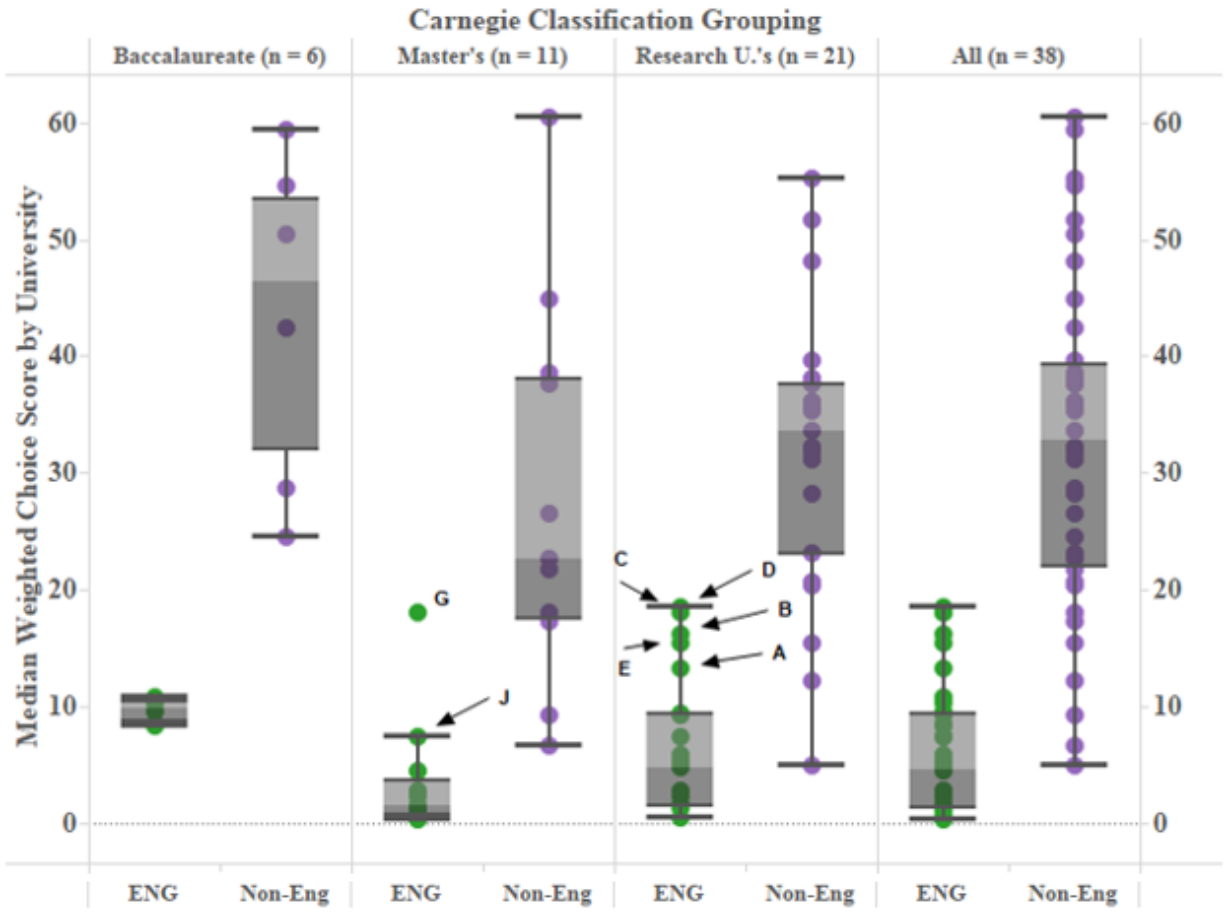
$_{psychology}$ = 112). Again, based on the normalized 130 degree credit hour total, these *overall* median values represent non-engineering students choosing 74% of their total degree courses, versus 40% for engineering students. As seen with the comparison of free elective opportunities, these data suggest that engineering students overall receive fewer opportunities to choose their courses as compared to their non-engineering peers.

Also as seen with the free electives analysis, there are exceptions: three RU/VH universities with comparatively high median total choice values fall within the bottom quartile of the median non-engineering total choice values ($\tilde{x}$ = 96, 93, and 85, respectively), and are therefore *High Choice Exceptions*. The same was also true for one exceptional engineering school in the Baccalaureate Colleges category ($\tilde{x}$ = 77). Though uncommon, these schools demonstrate the possibility of minimized *disparity* between engineering and non-engineering students in terms of their frequency of encountering course choice opportunities.

Weighted Choice Scores ("weighted choice")

Weighted Choice Score (calculated from the weighted matrix design presented in Table 2.4) adds a dimension of *magnitude* to the total choice frequency counts above, and captures not only the total number of courses students get to choose in a given degree program but also the depth of those choices in terms of the number of courses they get to choose from. Results of the median weighted choice values for engineering and non-engineering degree programs (by university) are presented within the three aggregated Carnegie Classification groupings in Figure 2.3.

Figure 2.3: Median engineering versus non-engineering Weighted Choice Scores by university across three Carnegie Classification aggregations.



Note: Labels A, B, C, D, E, G, and J identify High Choice Exception university data points. See Table 2.6.

The median Weighted Choice Score for engineering degree programs across all universities was 4.6 ($\tilde{x}_{\text{Bacc ENG}}$ = 9.9, $\tilde{x}_{\text{Mast. ENG}}$ = 1.6, $\tilde{x}_{\text{RU/VH ENG}}$ = 4.7), versus 32.9 for non-engineering degree programs ($\tilde{x}_{\text{Bacc NonENG}}$ = 46.4, $\tilde{x}_{\text{Mast. NonENG}}$ = 22.7, $\tilde{x}_{\text{RU/VH NonENG}}$ = 33.5). There were again considerable differences in weighted choice evident across non-engineering degree types ($\tilde{x}_{\text{physics}}$ = 21, $\tilde{x}_{\text{chemistry}}$ = 24, $\tilde{x}_{\text{mathematics}}$ = 32, $\tilde{x}_{\text{economics}}$ = 36, $\tilde{x}_{\text{psychology}}$ = 39); differences were

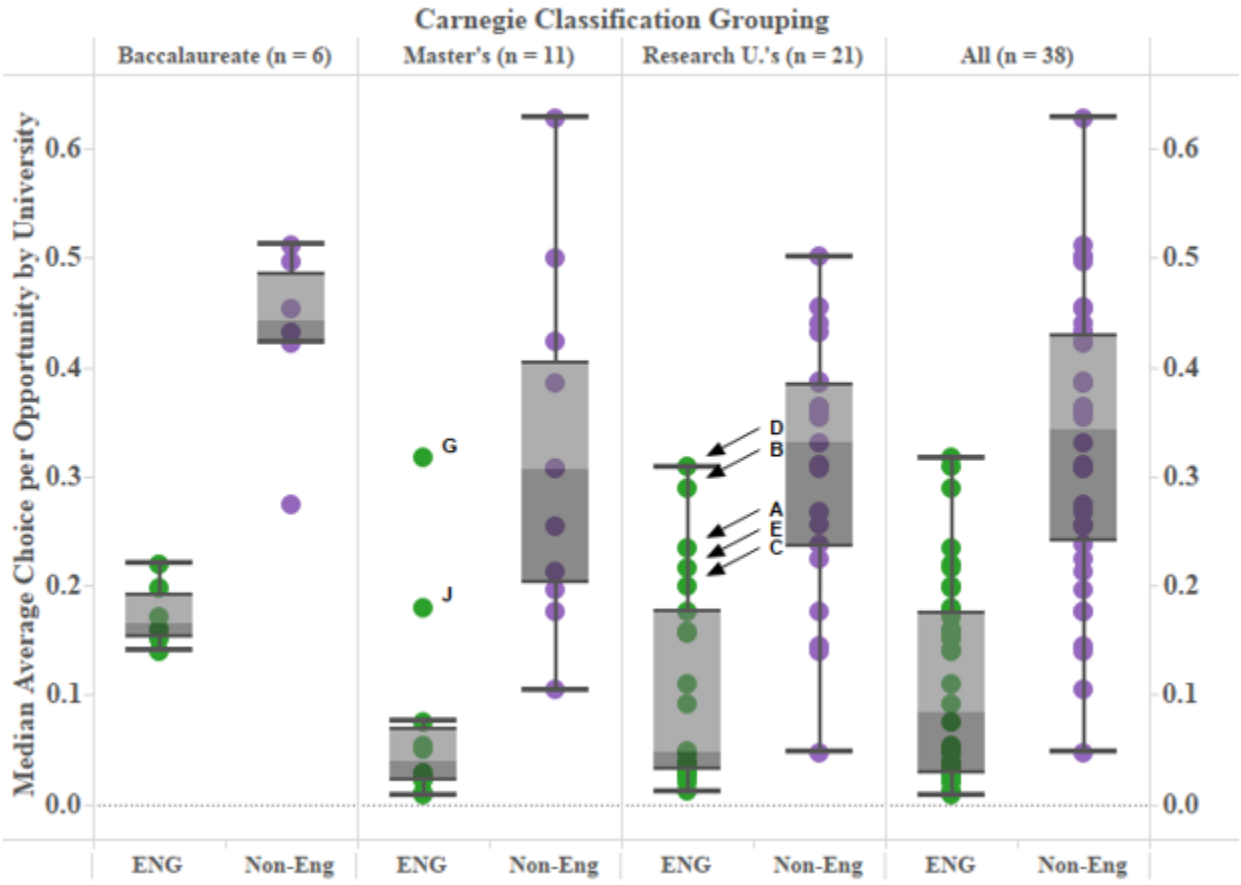
minimal between engineering degree types. As with free elective opportunities and the frequency of choice opportunities, these data suggest that mainstream engineering students also experience less *magnitude* of course choice opportunity.

Six *High Choice Exceptions* exist for weighted choice values, four RU/VH ($\tilde{x}$ = 18.4, 18.1, 16.2, and 13.2 respectively) and two Master's ($\tilde{x}$ = 18.0 and 7.4, respectively). Though these schools demonstrate comparatively increased weighted choice for engineering students, these exceptional values are still well below the typical weighted choice experienced by the non-engineering students.

Average Choice per Opportunity

Results of the median Average Choice per Opportunity values for engineering and non-engineering degree programs (by university) are presented within the three aggregated Carnegie Classification groupings in Figure 2.4.

Figure 2.4: Median engineering versus non-engineering Average Choice per Opportunity scores by university across three Carnegie Classification aggregations.



Note: Labels A, B, C, D, E, G, and J identify High Choice Exception university data points. See Table 2.6.

Here again, the engineering students get considerably less choice: the median Average Choice per Opportunity value for engineering degree programs across all universities was 0.08 ($\tilde{x}_{\text{Bacc ENG}}$ = 0.17, $\tilde{x}_{\text{Mast. ENG}}$ = 0.05, $\tilde{x}_{\text{RU/VH ENG}}$ = 0.05), versus 0.34 for non-engineering degree programs ($\tilde{x}_{\text{Bacc NonENG}}$ = 0.44, $\tilde{x}_{\text{Mast. NonENG}}$ = 0.31, $\tilde{x}_{\text{RU/VH NonENG}}$ = 0.33), again with differences evident across non-engineering disciplines ($\tilde{x}_{\text{physics}}$ = 0.28, $\tilde{x}_{\text{chemistry}}$ = 0.35, $\tilde{x}$

$\tilde{x}_{\text{economics}}$ = 0.35, $\tilde{x}_{\text{mathematics}}$ = 0.37, $\tilde{x}_{\text{psychology}}$ = 0.40). This result is not surprising in light of the previously presented unfavorable course choice opportunity disparity that engineering students experience in terms of *weighted* and *total* choice, the two dimensions of choice included in the Average Choice per Opportunity calculations. However, these results add some detail to the emerging understanding of the engineering student experience of course choice: the engineering students have fewer opportunities to choose their courses (as compared to their peers) and the opportunities they do have are more restricted—on average, the engineering students even have less choice *within* their choices.

As with each of the three other course choice metrics, there are exceptions: seven *High Choice Exceptions* exist for Average Choice per Opportunity values, five RU/VH ($\tilde{x}$ =0.31, 0.29, 0.23, 0.22, and 0.20 respectively) and two Master's ($\tilde{x}$ = 0.32 and 0.18 respectively).

Significant Course Choice Disparities Between Engineering and Non-Engineering Programs

We have seen differences between engineering and non-engineering student experiences of course choice opportunity in terms of each of the four metrics, but are these differences statistically significant? The pair-wise nonparametric Wilcoxon Signed Rank test ($\alpha = 0.05$) was used to detect statistically significant differences between engineering versus non-engineering choice variable values (since these values are *by university* and therefore represent two dependent groups of ordinal data) for each of the Carnegie Classification aggregations (Table 2.5).

Table 2.5. Median choice variable values and Wilcoxon Signed Rank p-values by Carnegie Classification grouping.

Choice Variable	Carnegie Classification Grouping			
	Baccalaureate	**Master's**	**Research U.'s**	**All**
Total Free Elective Credit Hours	$\tilde{x}_{ENG} = 7.9$ $\tilde{x}_{Non\text{-}Eng} = 44.7$ **p = 0.028***	$\tilde{x}_{ENG} = 0.0$ $\tilde{x}_{Non\text{-}Eng} = 20.8$ **p = 0.003***	$\tilde{x}_{ENG} = 4.4$ $\tilde{x}_{Non\text{-}Eng} = 32.5$ **p = 0.000***	$\tilde{x}_{ENG} = 3.7$ $\tilde{x}_{Non\text{-}Eng} = 31.4$ **p = 0.000***
Total Choice Count	$\tilde{x}_{ENG} = 56.4$ $\tilde{x}_{Non\text{-}Eng} = 99.5$ **p = 0.028***	$\tilde{x}_{ENG} = 42.0$ $\tilde{x}_{Non\text{-}Eng} = 88.5$ **p = 0.003***	$\tilde{x}_{ENG} = 60.1$ $\tilde{x}_{Non\text{-}Eng} = 102.7$ **p = 0.000***	$\tilde{x}_{ENG} = 51.6$ $\tilde{x}_{Non\text{-}Eng} = 97.5$ **p = 0.000***
Weighted Choice Score	$\tilde{x}_{ENG} = 9.9$ $\tilde{x}_{Non\text{-}Eng} = 46.4$ **p = 0.028***	$\tilde{x}_{ENG} = 1.6$ $\tilde{x}_{Non\text{-}Eng} = 22.7$ **p = 0.003***	$\tilde{x}_{ENG} = 4.7$ $\tilde{x}_{Non\text{-}Eng} = 33.5$ **p = 0.000***	$\tilde{x}_{ENG} = 4.6$ $\tilde{x}_{Non\text{-}Eng} = 32.9$ **p = 0.000***
Average Choice per Opportunity	$\tilde{x}_{ENG} = 0.17$ $\tilde{x}_{Non\text{-}Eng} = 0.44$ **p = 0.028***	$\tilde{x}_{ENG} = 0.05$ $\tilde{x}_{Non\text{-}Eng} = 0.31$ **p = 0.003***	$\tilde{x}_{ENG} = 0.05$ $\tilde{x}_{Non\text{-}Eng} = 0.33$ **p = 0.000***	$\tilde{x}_{ENG} = 0.08$ $\tilde{x}_{Non\text{-}Eng} = 0.34$ **p = 0.000***

*Statistically significant p-values ($\alpha = 0.05$).

Results of the Wilcoxon Signed Rank tests indicate that in *all cases* statistically significant differences exist between engineering and non-engineering degree programs in terms of each choice variable: Total Free Elective Credit Hours, Total Choice Count, Weighted Choice Score, and Average Choice per Opportunity. These results suggest a significant national trend of course choice *disparities* between engineering and non-engineering students, with engineering students experiencing significantly less course choice opportunity than their non-engineering peers.

Kruskal-Wallis nonparametric tests ($\alpha = 0.05$) were conducted to test for statistically significant differences between the three independent Carnegie Classification grouping populations (Baccalaureate Colleges, Master's Colleges and Universities, and Research

Universities) for each of the four choice variables. No statistically significant differences for any of the four choice variables were found between Carnegie Classification grouping populations—an indication that significant course choice disparities exist across all university-types.

The High Choice Exceptions (HCEs): Demonstrating Greater Course Choice Opportunity in Engineering

Despite the bleak overarching limited course choice opportunity trend in engineering, some engineering colleges are finding ways to provide their undergraduate students with more course choice opportunities. Ten *High Choice Exception* engineering schools (HCEs) whose median scores were comparatively high within one choice variable are listed in Table 2.6. For the purposes of this study, HCEs were defined as engineering schools whose median choice variable value(s) fell within the top quartile (or above) of median engineering scores *and* fell within or above the non-engineering bottom quartile of median values. HCEs were identified within each of the three Carnegie Classification groupings.

Table 2.6: The High Choice Exceptions: demonstrating comparatively high course choice opportunities in engineering schools across four choice variable categories.

Univ. Alias	Carnegie Class. Group	Institution Type	% Ugrad Pop. that is ENG*	# Accred. ENG Progs. at Univ.	$\tilde{x}_{ENG}$ *Total Free Elective Credit Hour* HCEs	$\tilde{x}_{ENG}$ *Total Choice Count* HCEs	$\tilde{x}_{ENG}$ *Weight. Choice Score* HCEs	$\tilde{x}_{ENG}$ *Average Choice per Opp.* HCEs
A	RU/VH[3]	Public	20	11	11	59	13.2	0.23
B	RU/VH[2]	Private	30	5	15	56	16.2	0.29
C	RU/VH[1]	Private	50	14	16	**93**	18.1	0.20
D	RU/VH[1]	Private	35	6	**17**	60	**18.4**	**0.31**
E	RU/VH[2]	Private	20	9	14	70	15.5	0.22
F	RU/VH[2]	Private	25	6	**25**	**96**	**25.2**	0.27
G	Master's[1]	Private	15	4	16	57	18.0	**0.32**
H	RU/VH[2]	Private	45	3	0	85	2.3	0.03
I	Bacc.[1]	Private	5	1	8	77	10.8	0.14
J	Master's[1]	Private	80	6	7	42	7.4	0.18
Median Across all ENG degrees					2	48	3.6	0.08
Median Across all Non-Eng degrees					31	98	32.9	0.34

[1]refers to "Small" institutions with total undergraduate populations under 5,000 students; [2]refers to "Medium" institutions with total undergraduate populations from 5,000 – 15,000 students; [3]refers to "Large" institutions with total undergraduate populations over 15,000 students (Collegedata, 2015)

*Rounded to the nearest 5% (US News & World Report, 2013)

Note: Shaded cells with bold font identify the two highest values for each choice variable.

Of the 65 accredited engineering degree programs offered across these ten engineering school HCEs all but one are engineering discipline-*specific* (such as aerospace, civil, electrical and mechanical) degree programs. In other words, these are *not* degree programs whose lack of engineering discipline-specific focus would lend itself to more possible course choice opportunities than could be possible for specialized degree programs. To the contrary, these are highly-ranked engineering colleges comprised of specialized engineering degree programs that

offer students greater course choice opportunity in spite of—or perhaps more aptly *in complement with*—engineering specialization.

Two schools, Universities C and F were HCEs across all four choice variables, indicating that these universities are autonomy-supportive of their engineering students in terms of every course choice opportunity dimension. At University C, for example, students get free electives (a minimum of 16 normalized credit hours for all engineering students), get to choose the majority of their courses, and get to choose their courses from comparatively large selections. For some engineering disciplines at University C, student course-choice-autonomy is *almost* at parity with the studied non-engineering degree program autonomy for the various choice metrics, but overall course choice opportunity is still lower for engineering students.

Four other universities (A, B, D, and G) were median engineering High Choice Exceptions in free electives, weighted choice, and Average Choice per Opportunity, but not in total choice, suggesting that the total number of courses engineering students get to pick is comparatively low. It is apparent from Table 2.6 that *there are numerous possible manifestations of course choice opportunities for engineering degree programs*, and therefore, a myriad of possibilities for engineering educators and leaders looking to infuse opportunities into their own undergraduate programs.

Notably, nine of the ten High Choice Exception schools are at Private institutions. It is further hypothesized that, as a group, the HCEs might have other similar distinguishing features. A Mann-Whitney U test was used to look for differences between the total number of tenured and tenure-track faculty members at the ten HCE versus 28 non-HCE institutions, motivated by the hypothesis that smaller faculty populations may be more likely to agree on and implement novel engineering baccalaureate programs, including those infused with more course choice and

flexibility. However, results showed no detectable differences in the faculty sizes for these two populations (p=0.960). In fact, the HCEs had a wide range of faculty sizes, from less than ten total tenured or tenure-track faculty members at the low end to almost 400 at the high end, with a median at 150 (ASEE, 2013).

It was also hypothesized that the HCEs may be home to newer engineering programs that came on-line in this outcomes-based accreditation era when flexibility is highly feasible from an accreditation standpoint. Again, however, results of a Mann-Whitney U test comparing the first year of ABET accreditation for the HCE versus non-HCE schools showed no detectable difference (p=0.256). Rather, eight of the ten High Choice Exception universities had their first accreditation in 1936, the same year as over half of the "other," non-HCE schools. If anything this analysis is more indicative of old, well-established engineering colleges perhaps having a "leg-up" in the US News & World Report rankings, which are based solely on peer assessment surveys (US News & World Report, 2013).

The ten exceptional high choice engineering schools were also not found to be more highly ranked *within* the total population of 38 institutions than the non-HCE schools (Mann-Whitney U p=0.279). Thus, despite some attempts to detect any other features that distinguish the High Choice Exceptional group of engineering schools, beyond their overwhelming tendency towards being private institutions, no other such features have been found yet, but this is an area of interest and will be the subject of future work.

Choice and Quality

Identification of these High Choice Exceptions is confirmation that it *is* possible for highly-ranked ABET-accredited engineering degree programs to provide significant course choice

opportunities to students. What remains to be seen is whether course choice opportunity can satisfy students' psychological need for autonomy in the same way that has been demonstrated for the power of choice in classroom learning activity outcomes (Deci et al, 1991; Jones, 2009; Jones and Wilkins, 2013; Ryan and Deci, 2000; Vanasupa, Solk, and Harding, 2010; Vanasupa, Stolk, and Herter, 2009), and if so, whether it could yield beneficial educational outcomes such as broadening participation, increased enrollment, and improved in-migration, retention and graduation rates. It further remains to be seen whether certain *types* of course choice opportunities yield greater psychological benefits (such as more free electives versus more total course choices or choices in technical courses versus humanities and social science electives, etc. or some combination) and would be more effective at improving educational outcomes.

University Median Choice Variable Ratios

Though we have now established that significant differences exist between engineering and non-engineering degree programs in terms of each choice variable, these results have yet to tell the story of the course choice *disparities* individual engineering students would encounter while matriculating at the respective 38 universities included in the comparative analysis. To paint this picture, choice variable median *ratios* between the non-engineering and engineering degree programs were calculated for each university. These values represent the difference in course choice opportunity that a student at a university would encounter in pursuit of the studied non-engineering degrees (chemistry, economics, math, physics, or psychology) as compared to the school's accredited engineering degrees. Higher ratios (greater than 1) represent *greater* disparities between non-engineering and engineering programs, and signify greater choice in the non-engineering degree programs. Conversely, ratio values less than 1 indicate greater choice in engineering degree programs than in the non-engineering degree programs. University choice

variable median ratios were calculated for each of the four choice variables individually. Equation 2.1 shows the median choice value ratio equation using the Total Free Elective Credit Hours variable example.

Equation 2.1: University median Total Free Elective Credit Hours (TFECH) ratio equation.

$$University\ Median\ TFECH\ Ratio = \frac{University\ Median\ NonEng\ TFECH}{University\ Median\ ENG\ TFECH}$$

Table 2.7 presents a summary of the university median course choice variable ratios and provides a sense of the state of course choice disparity between engineering and non-engineering students at the 38 universities included in this analysis.

Table 2.7: Summary of university median course choice variable ratios.

	Median *Total Free Elective Credit Hours* Ratios	**Median *Total Choice Count* Ratios**	**Median *Weighted Choice Score* Ratios**	**Median *Average Choice per Opportunity* Ratios**
Median	7.7	1.8	6.7	3.6
Maximum	45.5	3.7	77.0	29.8
Minimum	1.3	1.1	0.5	0.4

Across all universities, a median Total Free Elective Credit Hours choice opportunity disparity of 7.7 was found, indicating that the median of engineering students experience almost eight times *less* free elective credit hours than their non-engineering peers on campus. At all of the 38 studied institutions, non-engineering students were afforded a higher number of total free

electives than their engineering peers. At worst, engineering students had about 45 times less free electives than their non-engineering peers. High Choice Exception universities C and F (Table 2.6) were tied for the lowest median Total Free Elective Credit Hour ratio of 1.3, indicating that their engineering students experience far less disparity in the free elective choices they are afforded as compared to their non-engineering peers—just 1.3 times fewer free electives for the engineering students as compared to their non-engineering peers on campus.

The median Total Choice Count choice opportunity disparity across all universities was 1.8, indicating that the median of engineering students choose almost two times less of their total courses than their non-engineering peers on campus. This choice parameter had the least disparity between non-engineering and engineering degrees among the four choice parameters, an indication that engineering students in some cases get many chances to choose courses but those opportunities are not substantial, such as frequent category 1 choices, but minimal category 2, 3, and 4 choices (see Table 2.3). Here, universities C and H (Table 2.6) both had the lowest median Total Choice Count ratio of 1.1.

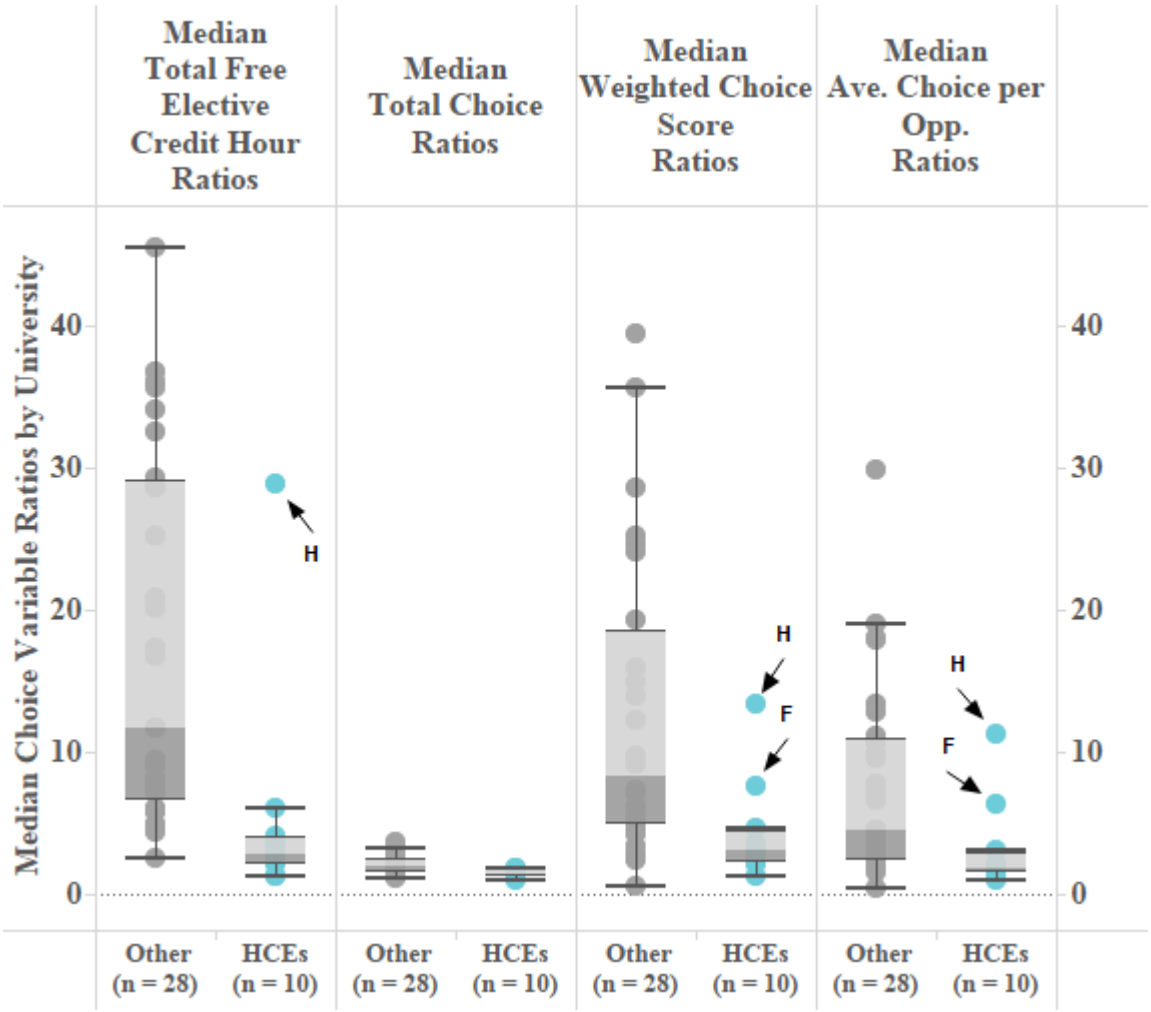
For Weighted Choice Score, the median choice opportunity disparity across all universities was 6.7, indicating that the median of engineering students experience 6.7 times less weighted choice opportunities over the course of their undergraduate experience as compared to their non-engineering peers on campus.

The median Average Choice per Opportunity choice opportunity disparity across all universities was 3.6, indicating that the median of engineering students experience 3.6 times less choice for each course choice opportunity as compared to their non-engineering peers on campus.

One university had median Weighted Choice Score and Average Choice per Opportunity ratios < 1 (see minimum values in Table 2.7), due to comparatively constrained non-engineering degree programs that had significant core curriculum requirements while engineering students were afforded several free elective credit hours. This university was not one of the ten HCEs, however, as all analyzed degree programs at the university still offered students low course choice opportunities overall compared to the other universities included in the study.

The median course choice variable ratios calculated by university for each of the four course choice variables is presented in Figure 2.5. It has been established that engineering students at the ten High Choice Exception universities experience more choice as compared to other *engineering* students in top-ranked programs across the country, but do the engineering students on these ten campuses also experience less choice disparity as compared to their *non-engineering* peers? Ratio values for the ten High Choice Exception universities are displayed in comparison to the ratio values for the remaining 28 non-HCE universities, referred to as "other."

Figure 2.5: Median choice variable ratios for High Choice Exception universities (HCEs) versus non-HCE universities ("Other").



Note: Two "Other" university Median Weighted Choice Score Ratios with values of 77.0 and 77.3, respectively, were omitted from this figure to aid in viewing the smaller median choice variable ratios.

Pair-wise Mann-Whitney U tests ($\alpha = 0.05$) were used to test for statistically significant differences in median choice variable ratios between HCE and non-HCE universities for each of the four choice variables (Table 2.8).

Table 2.8. Median choice variable ratios for HCEs versus non-HCEs and Mann-Whitney U p-values.

Total Free Elective Credit Hours	*Total Choice Count*	*Weighted Choice Score*	*Average Choice per Opportunity*
$\tilde{x}_{\text{Other}} = 11.7$ $\tilde{x}_{\text{HCE}} = 2.8$ **p = 0.001***	$\tilde{x}_{\text{Other}} = 1.9$ $\tilde{x}_{\text{HCE}} = 1.5$ **p = 0.004***	$\tilde{x}_{\text{Other}} = 8.3$ $\tilde{x}_{\text{HCE}} = 3.1$ **p = 0.002***	$\tilde{x}_{\text{Other}} = 4.5$ $\tilde{x}_{\text{HCE}} = 1.9$ **p = 0.008***

*Statistically significant p-values ($\alpha = 0.05$).

Results of the Mann-Whitney U tests indicate that statistically significant differences exist between High Choice Exception universities and non-HCE universities in terms of median choice variable ratios for every choice variable: Total Free Elective Credit Hours, Total Choice Count, Weighted Choice Score, and Average Choice per Opportunity.

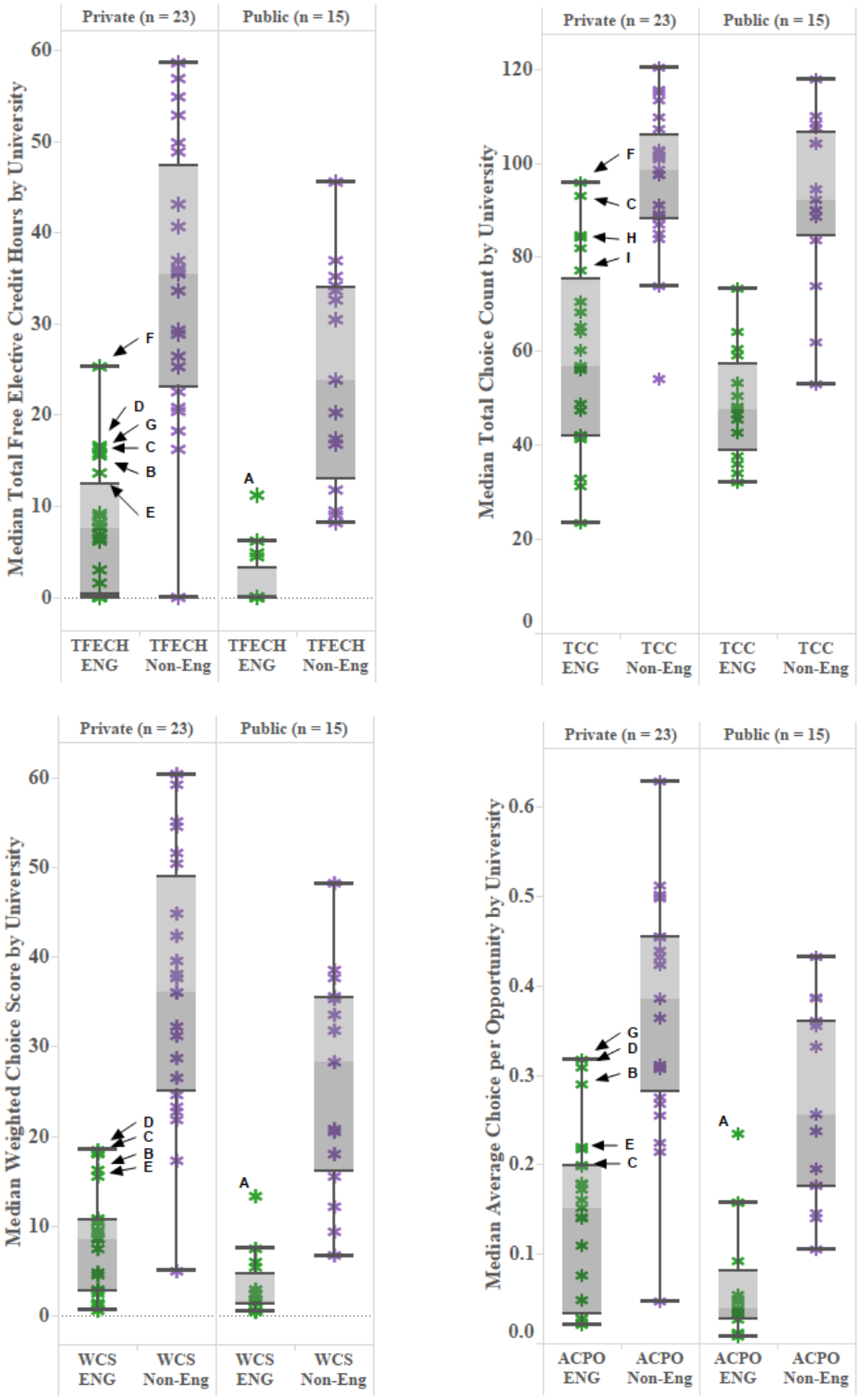
These results suggest that—for every choice metric—HCEs have *lower* median choice variable ratios than non-HCEs, meaning that the High Choice Exception schools not only offer their engineering students comparatively *more* course choice opportunity but also have *less* choice opportunity *disparity* between their engineering and non-engineering students. These HCE engineering students are getting more course choice opportunities *and* those choice opportunities are more comparable to those afforded to their non-engineering peers on campus.

Exploring Course Choice Opportunity at Public versus Private Institutions

In addition to Carnegie Classification aggregations, university median course choice variable data for engineering and non-engineering degree programs are also presented for public versus private institutions (Figure 2.6). These figures show that at the public institutions, the engineering degrees tend to have significantly less choice than non-engineering degrees, while

there is more overlap of choice metrics between engineering and non-engineering degrees at the private institutions.

Figure 2.6: Median course choice scores for 15 public versus 23 private universities.



Note: Labels A through I identify High Choice Exception university data points. See Table 2.6.

The Wilcoxon Signed Rank test ($\alpha = 0.05$) was used to detect statistically significant differences between engineering versus non-engineering choice variable values by university type (Table 2.9).

Table 2.9. Median choice variable values and Wilcoxon Signed Rank p-values for 23 private versus 15 public universities.

University Type	Choice Variable			
	Total Free Elective Credit Hours	***Total Choice Count***	***Weighted Choice Score***	***Average Choice per Opportunity***
Private	$\tilde{x}_{ENG} = 7.6$ $\tilde{x}_{Non\text{-}Eng} = 35.4$ **p = 0.001***	$\tilde{x}_{ENG} = 55.9$ $\tilde{x}_{Non\text{-}Eng} = 98.6$ **p = 0.001***	$\tilde{x}_{ENG} = 8.5$ $\tilde{x}_{Non\text{-}Eng} = 36.0$ **p = 0.001***	$\tilde{x}_{ENG} = 0.15$ $\tilde{x}_{Non\text{-}Eng} = 0.39$ **p = 0.001***
Public	$\tilde{x}_{ENG} = 0.0$ $\tilde{x}_{Non\text{-}Eng} = 23.8$ **p = 0.000***	$\tilde{x}_{ENG} = 47.6$ $\tilde{x}_{Non\text{-}Eng} = 92.1$ **p = 0.000***	$\tilde{x}_{ENG} = 1.6$ $\tilde{x}_{Non\text{-}Eng} = 28.2$ **p = 0.000***	$\tilde{x}_{ENG} = 0.04$ $\tilde{x}_{Non\text{-}Eng} = 0.26$ **p = 0.000***

*Statistically significant p-values ($\alpha = 0.05$).

Results of the Wilcoxon Signed Rank tests indicate that for both public and private university types, statistically significant differences exist between engineering and non-engineering degree programs in terms of every choice variable: Total Free Elective Credit Hours, Total Choice Count, Weighted Choice Score, and Average Choice per Opportunity. As was found with the Carnegie Classification aggregations (Table 2.5), the course choice opportunity disparity experienced by engineering students nationwide extends *across* university-type.

And, no detectable differences were found between the course choice opportunity disparities experienced by engineering students at public versus private institutions for three of the four choice variables. A Mann-Whitney U nonparametric test was conducted to test for statistically significant differences between the Public and Private populations, using median choice value *ratio* data (see example in Equation 2.1) and an α of 0.05. Median Total Choice Count, Weighted Choice Score, and Average Choice per Opportunity ratios were not significantly different between public and private universities. A statistically significant difference in median free elective ratios was found between public and private universities ($p = 0.03$), with larger median free elective ratios at public universities ($\tilde{x}_{\text{Public}} = 11.7$, $\tilde{x}_{\text{Private}} = 5.8$). These results indicate that for this population of universities, engineering students at public universities tend to experience a *greater* disparity with their peers in terms of the fewer free electives they are afforded as compared to students at private universities.

Again, a dispersion analysis was conducted, comparing the spread of ADM values for each of the four choice metrics between the 23 private and 15 public universities. Results were indicative of statistically significant differences in the variability of choice in terms of free electives ($p=0.001$), weighted choice ($p=0.014$), and Average Choice per Opportunity ($p=0.023$) between the public and private institutions (but not for total choice, where $p=0.052$). These results suggest that course choice opportunities for engineering students vary more from private university to private university than they do between public universities, where—as seen in Figure 2.6—the public universities revealed a more consistent tendency towards low choice for the population of schools included in this study.

Exploring Correlations Between Institution Variables and Course Choice Opportunity Data

Having explored the state of course choice opportunity in engineering schools nationwide and the significant choice opportunity disparities that undergraduate engineering students experience, we can begin to explore potential associations between university variables (such as population data or graduation rates) and their corresponding choice values. The nonparametric Spearman Rank Correlation statistical test was used to test for coefficients of association between ordinal-level institution variables and the ordinal-based choice variable ratio data generated in this study; results are summarized in Table 2.10. The table of critical values for Spearman's rho from Sheskin, 2003 was used to determine statistical significance based on sample size. Here, a conservative two-tailed level of significance of $\alpha = 0.01$ was used to identify the most significant correlations at values +/- 0.4 (signified by the flagged, highlighted cells in Table 2.10).

Table 2.10: Spearman's rho correlation coefficients for median choice variable ratios.

	US News & World Rank	**FT UG Population**	**% FT UG Pop. that is ENG**	**Univ. 6-year Grad. Rate**	***Total Free Elective Credit Hours* Med. Ratios**	***Total Choice Count* Med. Ratios**	***Weight. Choice Score* Med. Ratios**	***Ave. Choice per Opp.* Med. Ratios**
2013 US News & World Rank	1.000	-.003	**-.594***	-.253	.325	.366	.267	.160
FT UG Population	-.003	1.000	-.395	-.187	**.503***	.187	.397	.393
% FT UG Pop. that is ENG	**-.594***	-.395	1.000	.124	**-.513***	**-.490***	**-.492***	**-.401***
University 6-year Grad. Rate	-.253	-.187	.124	1.000	-.398	**-.475***	-.374	-.332
***Total Free Elective Credit Hour* Median Ratios**	.325	**.503***	**-.513***	-.398	1.000	**.453***	**.884***	**.862***
***Total Choice Count* Median Ratios**	.366	.187	**-.490***	**-.475***	**.453***	1.000	**.527***	.298
***Weighted Choice Score* Median Ratios**	.267	.397	**-.492***	-.374	**.884***	**.527***	1.000	**.948***
***Average Choice per Opportunity* Median Ratios**	.160	.393	**-.401***	-.332	**.862***	.298	**.948***	1.000

The percentages of full-time undergraduate populations that are engineering students was *negatively* correlated with 2013 US & World Report rankings. Because ranking values (1 = highest) are reverse from population counts, this negative correlation is indicative of *more highly-ranked engineering schools correlated with larger percentages of undergraduate populations that are engineering students*. In other words, the more engineering-focused schools (reflected in larger populations of engineering students) are more highly ranked.

Total Free Elective Credit Hour median ratios were *positively* correlated with full-time undergraduate population size, indicating that *larger schools are more likely to have greater free elective course choice opportunity disparities between engineering and non-engineering students*.

The percentage of the full-time undergraduate population that is engineering students is *negatively* correlated with each of the four median choice variable ratios, perhaps suggesting that more engineering-focused, technical institutions tend to have lower course choice opportunity disparities between engineering and non-engineering students.

Not surprisingly, the four choice variable median ratios are also highly correlative with one-another, with the exception of Total Choice Count median ratios and Average Choice per Opportunity median ratios.

University six-year graduation rate was *negatively* correlated with Total Choice Count median ratios. Though notable, because of the jump from degree-specific choice variable data to university-wide graduation data between these two metrics, it would be inappropriate to speculate on qualitative conclusions to draw from this correlation. As a reminder, these Total Choice Count median ratios were calculated (by university) from the median total choice in the studied non-engineering programs, divided by the median total choice in the accredited engineering programs. As such, only a handful of university offered degree programs are included in these calculations, versus the university six-year graduation rates that reflect *all* university degree programs.

The logical (and ideal) next step for this work is to further explore associations between university choice values and educational outcome metrics that could provide proxies for assessing the benefits of providing engineering students with choice, such as *degree program-*

specific GPAs and 6-year graduation rates. However, these university-specific data at the degree program level are oftentimes not publicly available and would require a tremendous (and unlikely) multi-university cooperative initiative to share data that, in some cases, may be less than flattering. Even so, future work will include attempting to seek data from the identified High Choice Exception universities to begin exploring these associations.

Discussion, Conclusions, Future Work

This study provided a multidimensional quantitative delineation of the course choice opportunities undergraduate students experience as they matriculate through various degree programs. Findings suggest a substantial overall national trend of course choice opportunity *disparities* between engineering and non-engineering students through the lens of each of the four course choice variables created for this study, Total Free Elective Credit Hours, Total Choice Count, Weighted Choice Score, and Average Choice per Opportunity, in each case with engineering students experiencing considerably *less* choice than their non-engineering peers.

The psychological impact(s) of this course choice opportunity disparity on undergraduate engineering students is unknown, but Self Determination Theory research is clear—autonomy-unsupportive educational environments *not only* miss out on the profound benefits of mindfully offering students choices, but stand to hinder developmental processes, and foster feelings of alienation, ill-being, and demotivation (Deci et al., 1991; Ryan and Deci, 2000). It is reasonable to hypothesize that restrictive engineering programs with little student choice might have lower retention of those engineering students who desire more autonomy and choice. At institutions where non-engineering degrees offer significantly more choice, undergraduate students desirous

of self-determination might be attracted to those non-engineering programs. These hypotheses have not yet been tested.

Findings from this study also indicate that this tendency towards highly-restrictive engineering degree program designs is *unnecessary* from an accreditation standpoint: exceptional accredited and highly prestigious undergraduate engineering degree programs exist that are autonomy-supportive in terms of providing comparatively more course choice opportunities to students. This study identified ten *High Choice Exception (HCE)* engineering schools, wherein engineering degree programs afford considerably more course choice opportunities to their students with respect to one or more of the course choice variables. As a group, across all choice metrics, the HCEs not only offer engineering students comparatively *more* course choice opportunities but also have *less* choice opportunity *disparity* between their engineering and non-engineering students. Thus, these HCE engineering students are experiencing the freedom to choose more courses *and* their experience of course choice opportunity is more congruent with that of their non-engineering peers on campus. And, only one of the 65 engineering degree programs offered across the ten HCE schools is a broad engineering degree program—the remaining 98% are high course choice engineering discipline-*specific* degree programs. These HCEs confirm that highly-ranked EAC ABET-accredited specialized engineering degree programs and significant course choice opportunity are compatible. Thus, it is not only *possible* to afford students with both, but may even be *essential* for student development.

Still unknown is whether course choice opportunities can satisfy undergraduate students' psychological need for autonomy in the same way that has been demonstrated for the power of choice in classroom learning activity outcomes (Deci et al, 1991; Jones, 2009; Jones and Wilkins, 2013; Ryan and Deci, 2000; Vanasupa, Solk, and Harding, 2010; Vanasupa, Stolk, and

Herter, 2009), and if so, could yield tangible beneficial educational outcomes such as broadening participation, increased enrollment, and improved in-migration, retention, and graduation rates in engineering education. It further remains to be seen whether certain *types* of course choice opportunities yield greater psychological benefits (such as more free electives versus more total course choice opportunities versus some combination, etc.) and would be more effective at improving educational outcomes. Borrowing a concept from economics, with choice, there is a point of diminishing returns; choice research tells us that, though some choice is essential, too much choice is not a good thing (Schwartz, 2004). With course choice opportunity, then, we still need to find out the psychologically optimal magnitude and frequency.

Remembering that engineering suffers from a low rate of migration into the major (Ohland et al., 2008), it is reasonable to hypothesize that increasing free elective opportunities in engineering degree programs may support greater in-migration of students, allowing students to switch into engineering with a greater chance of maintaining on-time graduation. Free elective opportunities additionally provide students with a greater ease of pursuing minors and certificates, which allow students to explore their unique interests and develop skillsets that may be complementary to their primary degrees and an asset to their careers. Further research is also needed to answer these questions and test these ideas.

Regardless of the answers to these higher-level questions it would seem—based on Self Determination Theory findings and the possibilities highlighted by the High Choice Exception universities—that we have strong evidence to support bettering student pathways through undergraduate engineering education with individual well-being in mind: if we can give students more choice, we should.

CHAPTER 3

COURSE CHOICE OPPORTUNITY IN SPECIALIZED ENGINEERING DEGREE PROGRAMS: RETHINKING UNDERGRADUATE ENGINEERING TO BETTER SUPPORT STUDENT PSYCHOLOGICAL NEED

Abstract

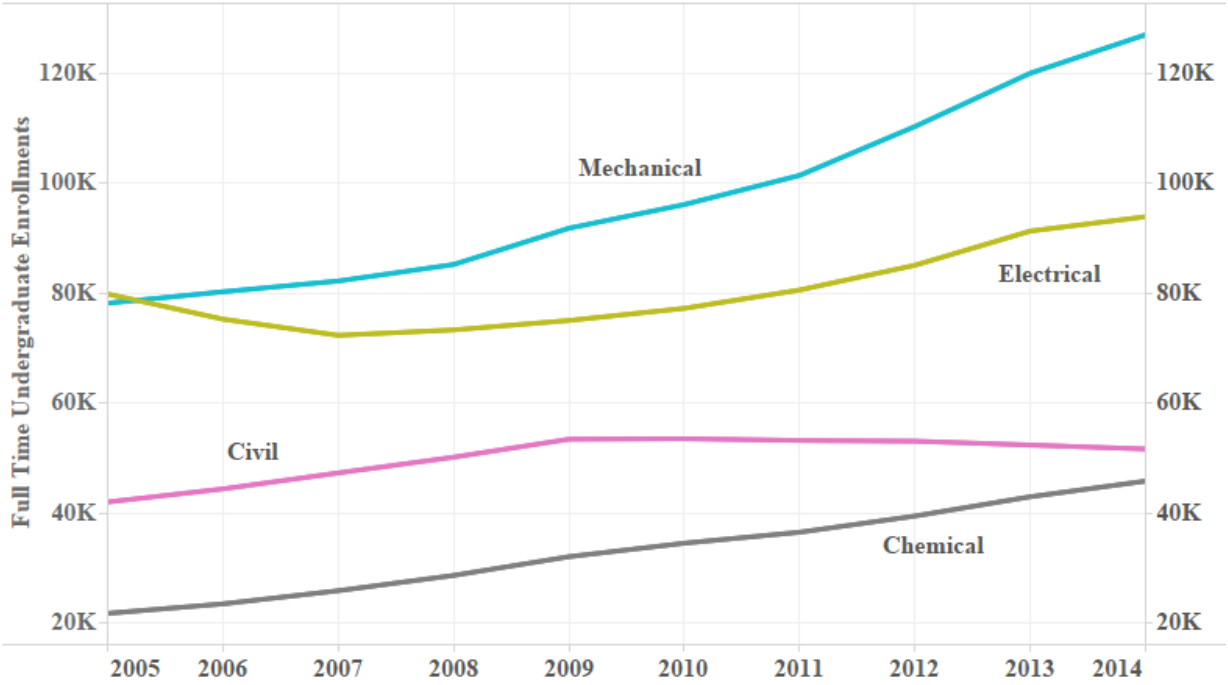
Previous studies have demonstrated that minimal *course choice opportunity* (such as free elective, technical elective, and humanities elective opportunities etc.) is prevalent in undergraduate engineering degree programs, and hypothesized that this low course choice culture is incompatible with students' psychological and developmental needs. The current study builds upon this work by delineating course choice opportunity *within* four engineering disciplines (chemical, civil, electrical, and mechanical engineering), and provides insight into the possibilities for infusing common, discipline-based undergraduate engineering degree programs with increased course choice opportunity. Course choice opportunities are explored for 83 top-ranked chemical, civil, electrical, and mechanical engineering programs that span 34 universities across the United States. Results suggest that course choice opportunity for these mainstream engineering degree programs tends to be low overall, but standout programs exist within each engineering discipline that offer students considerably more choice in terms of each of the four course choice metrics. Five universities with engineering degree program(s) that have the highest course choice variable value(s) across the four engineering program-types are highlighted, demonstrating the possibility of a compelling combination: ABET-accredited top-ranked specialized engineering degree programs that also foster autonomy-supportive environments for students in terms of course choice opportunity. These exceptional programs offer students a median of 17 normalized credit hours of *free* electives (out of a total of 130 credit hours), and

grant students the opportunity to make *choices* in a median of over over 75% of their total undergraduate degree.

Background

Over the last year, the number of engineering bachelor's degrees awarded grew by six percent, reaching just over 99,000 (ASEE, 2014). A look at full time undergraduate enrollments for four commonly-offered engineering programs—chemical, civil, electrical, and mechanical engineering—is a window into the varying growth from discipline to discipline. From 2009 – 2014 full time undergraduate enrollment in mechanical engineering increased by 39% while chemical engineering enrollments increased by 53% (Table 3.1) (ASEE, 2014). Following a decline leading up to 2007, electrical engineering enrollment also increased by 23% from 2007 – 2014, however in civil engineering enrollment has decreased since 2011 and is currently below 2009 levels (ASEE, 2014).

Table 3.1. United States undergraduate engineering enrollments for 2005 - 2014.



Note: Figure based on enrollment data from the American Society of Engineering Education (ASEE, 2014).

Regardless of overall growth in engineering, engineering educators must continually be mindful of opportunities improve the quality of engineering education, broaden participation, and attract and effectively educate engineers. These quality improvements stand to be more impactful if thoughtfully designed in concert with the ingredients of personal fulfillment, a process that demands thinking critically and creatively about undergraduate engineering degree programs from the perspective of the *students*.

Undergraduate students arrive furnished with innate and undeniable psychological (Deci et al., 1991; Ryan and Deci, 2000) and developmental (Watson and Froyd, 2007) needs to experience autonomy and make their own choices. It is logical to surmise that this basic human need for autonomy, the desire to feel a sense of volition in one's acts (Ryan and Deci, 2000), is

prone to bleed into student desires to experience the opportunity to explore academically over the course of the undergraduate years—years during which engineering students watch their non-engineering peers follow their passions or interests (within or outside their major) with the ability to choose many of their courses (Forbes, Bielefeldt, and Sullivan, 2015; Forbes et al., 2015).

Yet, by and large, undergraduate engineering degree programs are constrictive and thereby hypothesized to be unsupportive of students' psychological need for autonomy in terms of course choice opportunities (Forbes, Bielefeldt, and Sullivan, 2015; Forbes et al., 2015). The rigid oftentimes lock-step nature of many engineering programs is understandable given the seemingly impossible order for undergraduate programs to prepare well-rounded graduates with the necessary knowledge, skills, and competencies for a professional degree amidst longstanding pressures to decrease total credit hours over the same 4-year period (Russell, Stouffer, and Walesh, 2000). Faced with less credit hours and the need to impart a complex, evolving skillset to engineering students, flexibility in these engineering degree programs has long since been diminished, with free electives commonly eliminated (Epstein, 1991).

Though the Accreditation Board for Engineering and Technology's (ABET) move to an outcomes-based accreditation under the Engineering Criteria 2000 (EC 2000) criteria had the goal of both updating required competencies for engineering programs *and* increasing the flexibility of how programs reached their educational objectives, it appears that many engineering colleges have not taken advantage of this implicit opportunity for increased curricular flexibility and the possible benefits to students of so doing. Previous studies determined that there is a considerable difference in course choice opportunity between engineering and non-engineering undergraduate students on American campuses nationwide, with engineering students on most of the dozens of campuses studied afforded far less choice in

their undergraduate course selections than their peers across campus (Forbes, Bielefeldt, and Sullivan, 2015; Forbes et al., 2015). These studies also established that, though this potentially detrimental inclination towards constrictive engineering programs continues to flourish, some prestigious universities have found ways to minimize the course choice opportunity disparity gap through offering engineering students comparatively more choice opportunities within top-ranked (US News & World Report, 2013) ABET-accredited specialized engineering degree programs (Forbes, Bielefeldt, and Sullivan, 2015; Forbes et al., 2015). These findings present an obvious opportunity for systemic change in undergraduate engineering degree program design to better support students' developmental and psychological need for autonomy by infusing programs with more course choice opportunities while maintaining demanding and reputable engineering education experiences.

While these previous studies offer insights into the state of course choice opportunity in undergraduate engineering as a whole, they stop short of describing the comparative state of course choice opportunity *within* specific engineering disciplines at the undergraduate level. Such is the nature of the current study, which delineates course choice opportunity within chemical, civil, electrical, and mechanical engineering disciplines across universities nationwide, and provides insight into the possibilities for re-thinking common, discipline-based undergraduate engineering degree programs by providing increased course choice opportunity.

Research Questions

- What is the extent of *course choice opportunities* afforded to undergraduate engineering students enrolled in the nation's top-ranked chemical, civil, electrical, and mechanical engineering degree programs?

- Are curricular choice and program quality at odds? Phrased differently, do top-ranked discipline-based undergraduate degree programs exist within chemical, civil, electrical, and/or mechanical engineering that offer substantial course choice opportunities to students?
- How do the course choices afforded to chemical, civil, electrical, and mechanical engineering students *within* the same engineering college compare to one another?
- Nationally, are certain engineering disciplines more inclined to be autonomy-supportive in terms of affording comparatively more course choice opportunities to students?

Methods

This study outlines the state of course choice opportunity for the 2015 US News & World Report top-ranked undergraduate schools in chemical, civil, electrical, and mechanical engineering programs using four quantitative course choice variables. Each of the degree programs included in this study is ABET-accredited through an outcomes-based approach. Because ABET does not require specific courses, it neither favors nor hinders engineering programs relative to course choice opportunity.

The first analysis presented includes the top-ranked programs at schools where the highest engineering degree offered is a doctorate (a later section of this chapter includes an analysis of engineering programs at universities where doctorate programs are not offered). The engineering specialties rankings for undergraduate schools studied where doctorate is the highest degree span a total of 34 universities and 83 total degree programs. Due to ties in rankings, sample sizes across engineering disciplines vary slightly and include 22 chemical engineering, 19 civil engineering, 20 electrical engineering, and 22 mechanical engineering programs. Each of these degree programs is housed in a university with the Carnegie Classification (Carnegie Classification of Institutions of Higher Learning, 2015) of "Research Universities (very high

research activity)" (RU/VH). The 34 universities include 12 private and 22 public institutions (see Table 3.2 for university undergraduate population and ABET-accredited degree program count data).

Table 3.2: Full time undergraduate population data for 34 universities with top-ranked engineering specialty degree programs.

Full Time U-grad Pop. (rounded to nearest 1000)*	N	% Full Time U-grad Pop. that is ENG*	N	# of ABET-accredited Engineering Degree Programs at University#	N
0 – 1,000	1	0 - 10	1	1 – 3	1
2,000 – 5,000	4	11 - 20	18	4 – 6	7
6,000 – 10,000	6	21 - 30	10	7 – 9	4
11,000 – 20,000	5	31 – 40	1	10 – 12	13
21,000 – 30,000	11	41 - 50	2	13 – 15	6
31,000 +	7	51 - 60	2	16 – 17	3

**ASEE, 2015*
#ABET, 2015

Course choice variable data for the 2015 US News & World Report top-ranked chemical, civil, electrical, and mechanical engineering programs at nine universities (see Table 3.3) where doctorate programs are *not* offered were compared to those of the top-ranked programs at schools where the highest engineering degree offered is a doctorate (the same 83 degree programs across 34 universities previously outlined). For the purposes of this study, the population of engineering degree programs at the 34 universities where doctorate is the highest degree will be referred to as "Doctoral," while the population of engineering degree programs at the nine universities where doctorates are not offered will be referred to as "No Doctoral." Though a total of 83 Doctoral ranked programs within chemical, civil, electrical, and mechanical

engineering were used for this study, only 20 No Doctoral programs are ranked in the same engineering specialties (two chemical engineering, four civil engineering, six electrical engineering, and eight mechanical engineering).

Table 3.3: Full time undergraduate population data for the nine universities where doctorate programs are not offered.

Full Time U-grad Pop. (rounded to nearest 1000)*	N	% Full Time U-grad Pop. that is ENG*	N	# of ABET-accredited Engineering Degree Programs at University#	N
0 – 1,000	3	0 - 10	1	1 – 3	2
2,000 – 5,000	4	11 - 20	2	4 – 6	4
6,000 – 10,000	0	21 - 40	1	7 – 9	2
11,000 – 20,000	2	40+	5	10 – 12	1

**ASEE, 2015*
#ABET, 2015

For each degree program, course choice opportunity data was gathered from the 2013-2014 online university catalog. As a continuation of a previous study on course choice opportunity in engineering (Forbes et al., 2015), this work utilizes four course choice variable metrics for a multi-dimensional delineation of course choice opportunity within each studied degree program, including: *Total Free Elective Credit Hours* ("free electives"), *Total Choice Count* ("total choice"), *Weighted Choice Score* ("weighted choice"), and *Average Choice per Opportunity*.

The universities included in this study have varied methods of quantifying the courses that students take as part of their degree programs. For example, one university does not use credit hours as part of their system, and instead requires a total of 34 courses for their Bachelors

of Science degree programs in engineering, where each course counts for one of the 34 course requirement. Other universities vary from quarter to semester methods and have a wide range of credit hour requirements all the way up to the 515 credits required for an undergraduate degree at one university. Due to these varied metrics, in all cases, course choice opportunity data were normalized to 130 total degree credit hours (a continuation of the established method based on the median total degree credit hour value from Forbes et al., 2015). For example, a 3 credit hour free elective course choice opportunity as part of a 120 degree program would be normalized to 3.3 credit hours in a 130 credit hour degree program as follows: 3 * (130 / 120) = 3.3. The same credit hour normalization method was used throughout this study.

Total Free Elective Credit Hours ("free electives")

Total Free Elective Credit Hours represents the sum of all credit hours out of the 130 credit hour total for which students are free to choose *any* course. No restrictions are placed on these course selections.

Total Choice Count ("total choice")

Total Choice Count is the sum of *all* credit hours out of the 130 credit hour total for which students get to make *some kind of choice* in the course they take. These choices could include free electives, technical electives, humanities electives, etc., or simply getting to pick a writing class out of two writing course options.

Weighted Choice Score ("weighted choice"): The Weighted Matrix Design

Weighted Choice Score adds a dimension of magnitude to the Total Choice Count and is calculated using a weighted matrix (Tables 3.4 and 3.5). To calculate weighted choice for a given degree program, the course choice opportunity credit hours for the program were categorized as either: 1) courses chosen from a list of options, 2) courses chosen within one department, 3)

courses chosen across more than one department, or 4) free electives (Table 3.4), and entered into the corresponding categories in the weighted matrix (see cells **I**, **J**, **K**, and **L** in Table 3.5).

Table 3.4. Weighted Choice Score course choice opportunity categories.

Category	Definition	Examples	Weight
1	Courses chosen from a list of options.	"Choose 2 of the following 4 courses" "Choose one course from the following list of options"	3
2	Courses chosen from one department *or* engineering electives.	"Physics elective," "History elective," "Mechanical Engineering elective"	22
3	Course choices outside of engineering, chosen from more than one department (but not a free elective).	"social sciences elective," "humanities elective", "technical elective"	88
4	Free electives.	These course choice opportunities have no restrictions.	1292

Weights for each matrix category are designed to capture the magnitude of choice for each type of course choice opportunity. The weighted values used here (3, 22, 88, and 1292, respectively) originate from a five-university pilot study (Forbes, Bielefeldt, and Sullivan, 2015) wherein the actual numbers of courses students got to pick from for each course choice opportunity were counted (weights for the matrix used in this study are the median values resulting from the pilot-study). See Table 3.5 for the weighted matrix design and sample calculations of total choice and weighted choice.

Table 3.5. Weighted matrix design and example.

Degree Program	Cat. 1	Cat. 2	Cat. 3	Cat. 4	Total Choice Count	Weighted Choice Score
	3 **A**	22 **B**	88 **C**	1292 **D**		
	Weighted Fractions / 1292					
	.0023 **E**	.0170 **F**	.0681 **G**	1 **H**		
Civil Eng.	9 **I**	6 **J**	12 **K**	2 **L**	29 **M**	2.9 **N**

- Cells **A→D** contain the median values from the pilot study that comprise the basis for the matrix weighting.
- Cells **E→H** contain the actual weights used in the matrix, fractions calculated by individually dividing **A→D** by **D**.
- Cells **I→L** contain frequency counts (in credit hours) of the various four course choice categories. In this example, the Civil Engineering degree has 9 credit hours of Category 1 choices (**I**), 6 credit hours of Category 2 choices (**J**), 12 credit hours of Category 3 choices (**K**), and 2 credit hours of Category 4 choices (**L**).
- *Total Choice Count*: **M** = **I** + **J** + **K** + **L**.
- *Weighted Choice Score*: **N** = (**I*****E**) + (**J*****F**) + (**K*****G**) + (**L*****H**).

Average Choice per Opportunity

Average Choice per Opportunity represents the average magnitude of choice students experience for every course choice opportunity they are afforded, and is calculated by dividing Weighted Choice Score by Total Choice Count. For the example in Table 3.5, Average Choice per Opportunity = **N** / **M** = 2.9 / 29 = 0.10.

Microsoft Excel 2013 was used for data collection and calculations of university choice variable data for this study. Statistical analyses were performed using MVPstats, and in all cases were two-tailed with significance levels of $\alpha = 0.05$.

Results

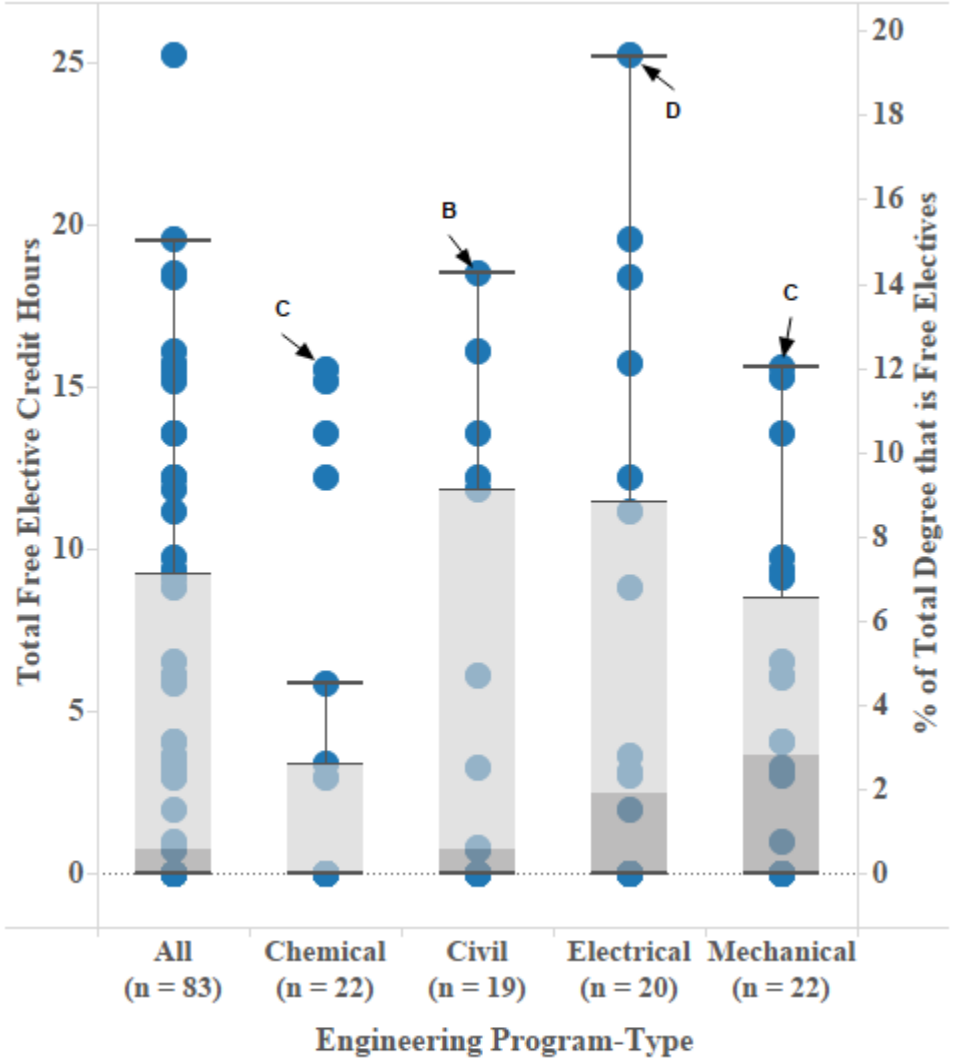
Choice Comparisons at Doctorate-Awarding Institutions

Course choice variable data for the top-ranked chemical, civil, electrical, and mechanical engineering degree programs at schools where the highest degree offered is a doctorate are presented for the four choice variables in Figures 3.1 – 3.4 and Tables 3.6 – 3.9.

Total Free Elective Credit Hours ("free electives")

Total Free Elective Credit Hour values for the top-ranked four engineering program-types are presented in Figure 3.1 and Table 3.6. Free electives for each of the 83 specialized engineering degree programs are shown as unique points to show values for individual universities. An overlaid box and whisker plot displaying the minimum, maximum, upper and lower quartile, and median values for each engineering discipline provides for comparison across program-types.

Figure 3.1: Total Free Elective Credit Hour scores by university for engineering programs at doctoral institutions.



Note: Labels B, C, and D identify the highest choice variable value standout universities. See Tables 3.10 and 3.11.

Table 3.6. Total Free Elective Credit Hour median values for engineering programs at doctoral institutions.

Engineering Program-Type					Kruskal-Wallis
All	Chemical	Civil	Electrical	Mechanical	
$\tilde{x}_{All}$ = 0.8 (n = 83)	$\tilde{x}_{Chem}$ = 0.0 (n = 22)	$\tilde{x}_{Civil}$ = 0.7 (n = 19)	$\tilde{x}_{Elec}$ = 2.5 (n = 20)	$\tilde{x}_{Mech}$ = 3.7 (n = 22)	**p = 0.415**

Almost half (n = 40) of the 83 top-ranked programs offered *no* free elective course choice opportunities to their engineering students: 16 chemical engineering, eight civil engineering, nine electrical engineering, and seven mechanical engineering degree programs. The students enrolled in these engineering programs never experience the freedom to explore academically with an unrestricted course selection.

On the other end of the spectrum, 12% (n = 10) of the programs offered students *over* 15 normalized credit hours of free electives as a part of their 130 credit hour undergraduate experience: two chemical engineering, two civil engineering, four electrical engineering, and two mechanical engineering degree programs. These 15 credit hours represent at least five semesters during which students could somewhat follow their passions and choose one three credit-hour course of their liking—a marked difference in collegiate academic experience as compared to students who never get to choose a free elective over the course of their undergraduate career.

The universities offering the most free elective credit hours to students for each of the four engineering program-types are highlighted and discussed in a later section of this chapter (the highest values for the other choice metrics are also discussed).

A Kruskal-Wallis nonparametric test revealed that, for the programs studied, no statistically significant differences exist between chemical, civil, electrical, and mechanical degree program Total Free Elective Credit Hour values, indicating that these four engineering program-types, overall, tend to afford equivalent free elective credit hour opportunities to students. In all four cases, these engineering disciplines offer medians of less than 4 credit hour

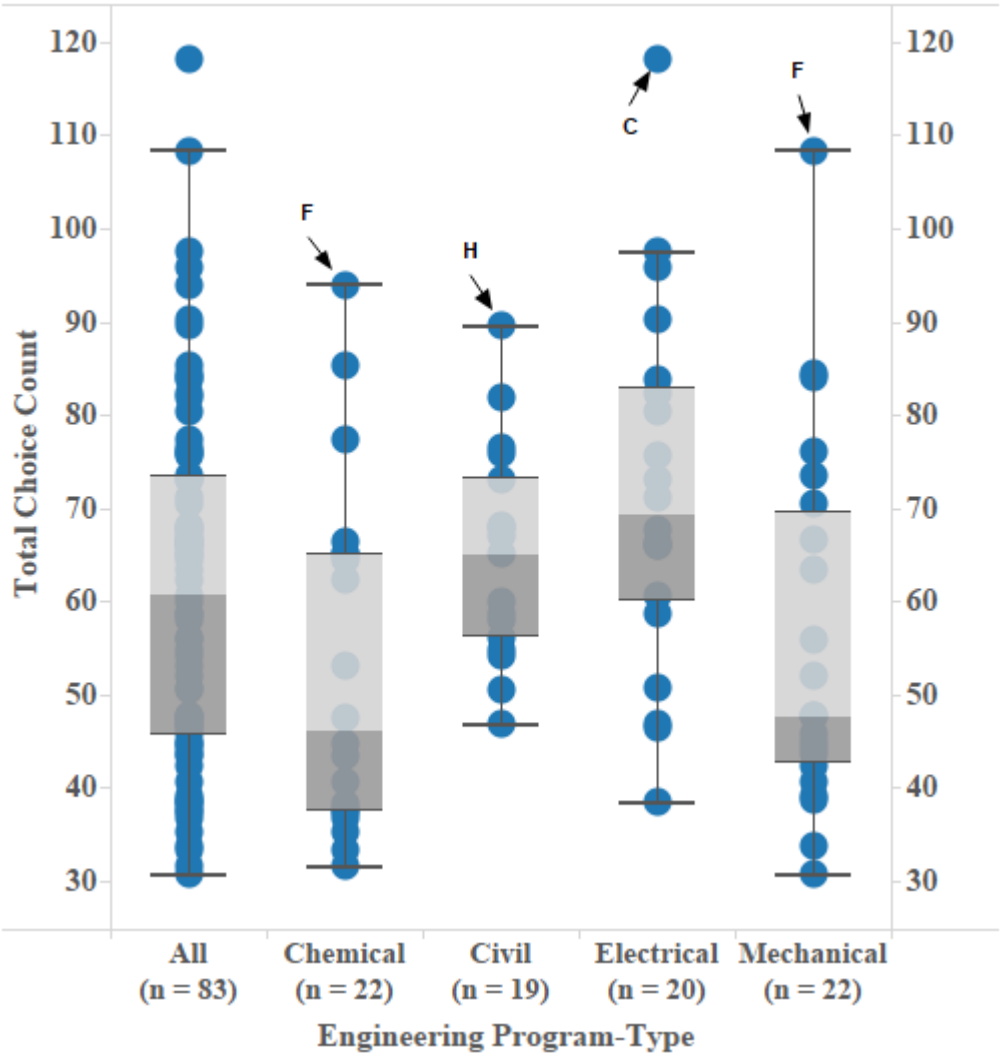
electives. These findings suggest that low free elective choices are prevalent in engineering programs nationwide, and are not unique to one discipline, but rather extend *across* disciplines.

A Kruskal-Wallis test on Absolute Deviation from Median (ADM) scores was used to compare the spread of free elective credit hour opportunities across the four engineering disciplines. Results were indicative of a statistically significant difference in the variations of free elective offerings between the disciplines ($p=0.012$). Mann-Whitney U post hoc tests ($\alpha=0.05$) revealed no detectable differences between the spread of free elective opportunities for civil, mechanical and electrical engineering programs, but less variability was found for chemical engineering, as compared to the three other disciplines. To summarize, these results suggest that the free elective credit hours allotted to students in chemical engineering are more consistent from program to program.

Total Choice Count ("total choice")

Total Choice Count values for the top-ranked four engineering program-types are presented in Figure 3.2 and Table 3.7.

Figure 3.2: Total Choice Count scores by university for engineering programs at doctoral institutions.



Note: Labels C, F, and H identify the highest choice variable value standout universities. See Tables 3.10 and 3.11.

Table 3.7. Total Choice Count median values for engineering programs at doctoral institutions.

Engineering Program-Type					Kruskal-Wallis
All	Chemical	Civil	Electrical	Mechanical	
$\tilde{x}_{All}$ = 60.7 (n = 83)	$\tilde{x}_{Chem}$ = 46.1 (n = 22)	$\tilde{x}_{Civil}$ = 65.0 (n = 19)	$\tilde{x}_{Elec}$ = 69.4 (n = 20)	$\tilde{x}_{Mech}$ = 47.7 (n = 22)	**p = 0.002***

*Statistically significant p-value (α = 0.05).

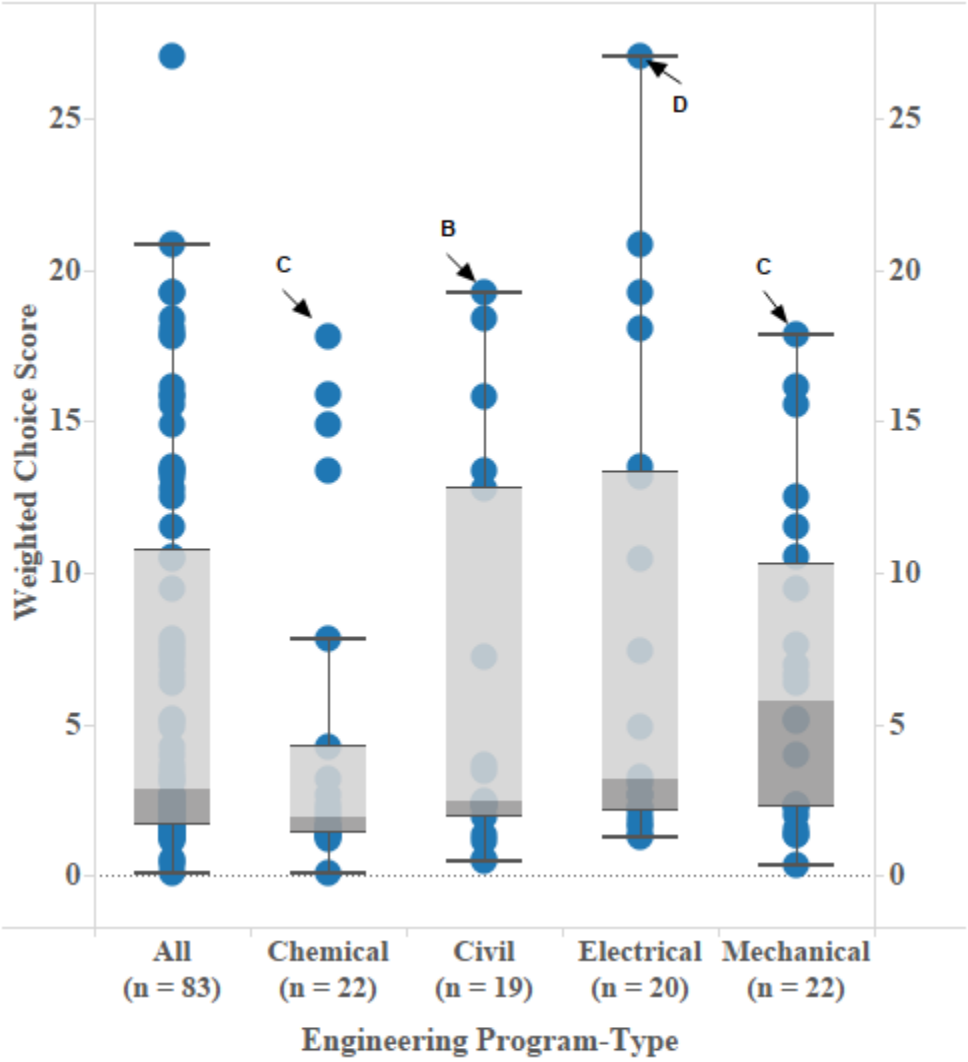
As seen in Table 3.7, each of the four engineering program-types had a median Total Choice Count value above 45 credit hours, indicating that the engineering students enrolled in the studied degree programs generally have some choice in about one-third of their courses. The program with the lowest total choice value offered students some choice in 30 credit hours of courses, which is still 23% of their overall degree.

Results of a Kruskal-Wallis test revealed that a statistically significant difference exists between chemical, civil, electrical, and mechanical degree program Total Choice Count values ($p=0.002$). Mann-Whitney U post hoc tests showed that the total choice for the chemical and mechanical engineering programs are equal to each other and the total choice for the civil and electrical engineering programs are equal, but that chemical and mechanical engineering programs have lower total choice than the civil and electrical engineering programs. In other words, these findings suggest that within the 83 programs studied, chemical and mechanical engineering students tend to experience *fewer* overall course choice opportunities than civil and electrical engineering students.

Weighted Choice Score ("weighted choice")

Weighted Choice Score values for the top-ranked four engineering program-types are presented in Figure 3.3 and Table 3.8.

Figure 3.3: Weighted Choice Scores by university for engineering programs at doctoral institutions.



Note: Labels B, C, and D identify the highest choice variable value standout universities. See Tables 3.10 and 3.11.

Table 3.8. Weighted Choice Score median values for engineering programs at doctoral institutions.

Engineering Program-Type					Kruskal-Wallis
All	Chemical	Civil	Electrical	Mechanical	
$\tilde{x}_{All}$ = 2.9 (n = 83)	$\tilde{x}_{Chem}$ = 1.9 (n = 22)	$\tilde{x}_{Civil}$ = 2.5 (n = 19)	$\tilde{x}_{Elec}$ = 3.2 (n = 20)	$\tilde{x}_{Mech}$ = 5.8 (n = 22)	**p = 0.223**

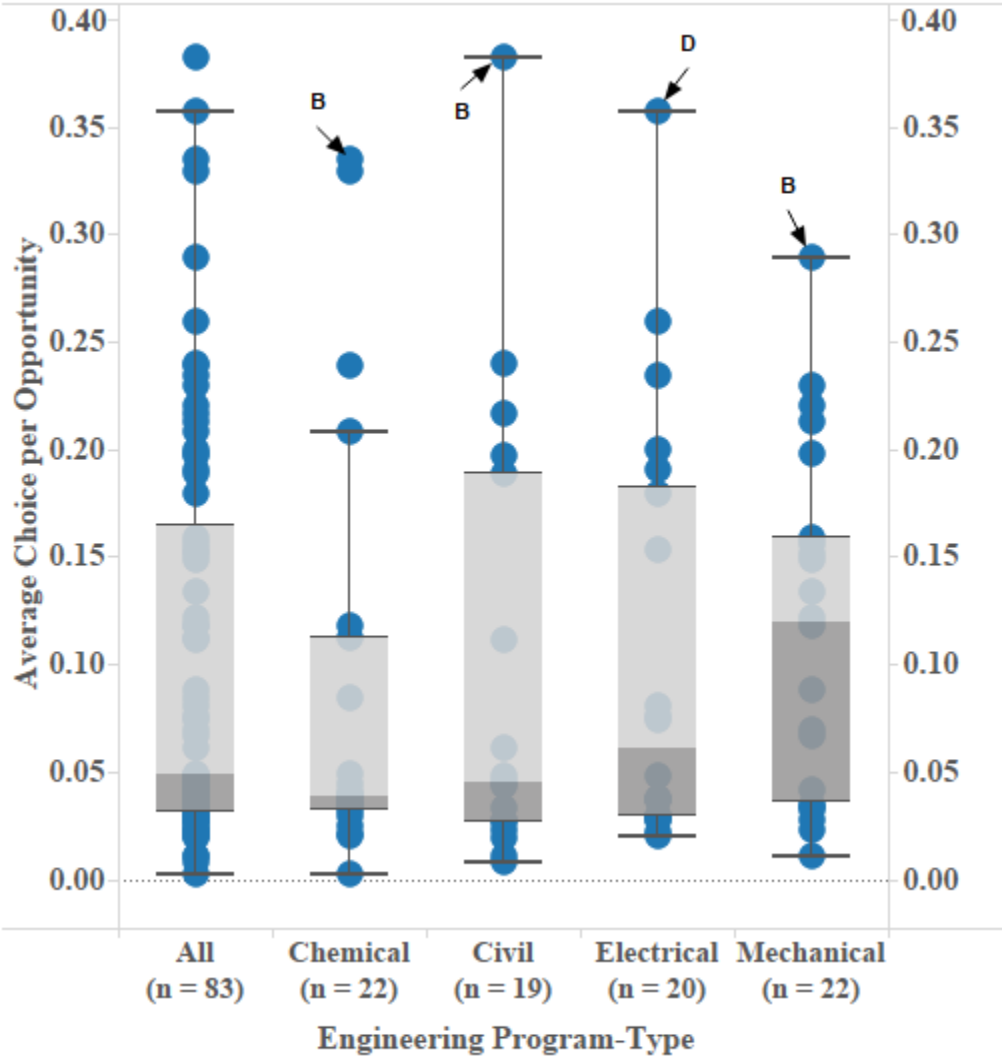
Across all of the 83 studied degree programs, the lowest Weighted Choice Score—capturing the *magnitude* of course choice that students experience—was 0.09. Each of the four engineering program-types had median weighted choice values below 6, which is unsurprising considering that the magnitude of this choice metric is predominated by large free elective weighting (see Table 3.4), and it has been established that these engineering students generally get few free elective course choice opportunities. These median weighted choice values are dreary, especially when considered in the context of the substantially higher weighted choice values found for non-engineering degree programs ($\tilde{x}$ = 33) from a previous study that used the same methods (Forbes et al., 2015).

Kruskal-Wallis test results revealed that no statistically significant differences exist between chemical, civil, electrical, and mechanical degree program weighted choice values, indicating that these four top-ranked engineering program-types tend to afford the same magnitude of course choice opportunities to students. To summarize, as was found with the free elective results outlined above, the low *magnitude* of course choice opportunity prevalent in undergraduate engineering programs extends across disciplines.

Average Choice per Opportunity

Average Choice per Opportunity values for the top-ranked four engineering program-types are presented in Figure 3.4 and Table 3.9.

Figure 3.4: Average Choice per Opportunity scores by university for engineering programs at doctoral institutions.



Note: Labels B and D identify the highest choice variable value standout universities. See Tables 3.10 and 3.11.

Table 3.9. Average Choice per Opportunity median values for engineering programs at doctoral institutions.

Engineering Program-Type					Kruskal-Wallis
All	**Chemical**	**Civil**	**Electrical**	**Mechanical**	
$\tilde{x}_{All}$ = 0.05 (n = 83)	$\tilde{x}_{Chem}$ = 0.04 (n = 22)	$\tilde{x}_{Civil}$ = 0.05 (n = 19)	$\tilde{x}_{Elec}$ = 0.06 (n = 20)	$\tilde{x}_{Mech}$ = 0.12 (n = 22)	**p = 0.548**

As with free electives and the weighted choice score, Kruskal-Wallis test results revealed that no statistically significant differences exist between chemical, civil, electrical, and mechanical degree program Average Choice per Opportunity values, suggesting that students in the studied engineering disciplines tend to experience equivalent magnitudes of choice (or lack thereof) for each course choice opportunity they experience. Generally low Average Choice per Opportunity values in all areas suggest that many of the choices these engineering students get to make are low-magnitude choices (such as choice category 1, a choice from a defined list of courses, and choice category 2, a choice from within a single discipline; see Table 3.4) and may not be very psychologically gratifying. The hypothesis that course choice opportunities with fewer options (such as "pick one of the following three courses") are less psychologically meaningful or autonomy-supportive to students as opportunities to select a course from many options (such as a free elective) has not yet been tested, but presents future qualitative work of interest.

Precisely how these findings translate into an ideal course choice opportunity recommendation for undergraduate engineering programs is not yet known. It is worth noting here, however, that choice research suggests that while *some* choice is essential and always a "good" thing, *more* choice is not always "better," and—like *no* choice—*too much* choice can also have unfavorable psychological consequences (Schwartz, 2004). In the pilot study that formed the basis for this current work, it was found that students across five universities choose their electives from a median of over 1000 courses (Forbes, Bielefeldt, and Sullivan, 2015). Given the potentially psychologically paralyzing effects of too much choice (Schwartz, 2004), it

is worth asking, for example, whether free electives provide students with too many options, missing the target for optimal psychological benefit. Or rather, whether the only potential psychological risk from free electives offerings is *not* the number of courses students can choose from but rather whether a degree program offers too many free elective opportunities overall (which it would seem that mainstream engineering programs are in no danger of doing). More work is therefore needed to not only establish *whether* increased course choice opportunities can yield beneficial educational outcomes (such as improved enrollments and graduation rates), but if so, *how* to best optimize those choices, including the most beneficial *types* of course choices as well as the optimal *frequency* and *magnitude* of those choices.

As was previously reported for total free elective credit hour opportunities, Kruskal-Wallis tests on Absolute Deviation from Median (ADM) scores were also used to compare the dispersion of total choice, weighted choice, and average choice opportunities across the chemical, civil, electrical, and mechanical engineering programs. For each of these three choice metrics, results revealed no detectable differences in the spread of choice opportunities experienced by students across the four engineering disciplines. For the studied population of degree programs, then, no differences were found in the variability of choice opportunities across the engineering disciplines in terms of total choice ($p=0.699$), weighted choice ($p=0.141$), or Average Choice per Opportunity ($p=0.164$).

Uppermost Choice Variable Values: Demonstrating Comparatively High Course Choice Opportunity in Specialized Engineering Program-Types

We have seen that the low course choice culture in undergraduate engineering extends across disciplines, with chemical, civil, electrical, and mechanical engineering students nationwide

commonly experiencing few (or zero) free electives, and especially minimal course choice opportunities in terms of weighted choice and Average Choice per Opportunity. The only detected difference in course choice opportunity experienced by these students across disciplines lies in the total *amount* of courses for which they are afforded some choice, with chemical and mechanical engineering students experiencing fewer course choice opportunities than civil and electrical engineering students. We have also seen—again, across disciplines—that standout programs exist that offer comparatively more course choice opportunities to students. These programs will now be highlighted, with the hope of expanding awareness of the more "choice-friendly" engineering academic experiences that demonstrate the possible concurrent embodiment of autonomy-supportive, reputable, accredited, and top-ranked undergraduate engineering discipline programs.

The *highest* choice variable values and *median* choice variable values for each engineering program-type from the 83 degree programs in the study are listed in Table 3.10.

Table 3.10. The highest choice variable values for four engineering program-types.

Engineering Program-Type	Choice Variable			
	Total Free Elective Credit Hours $\tilde{x}_{\text{All}} = 0.8$	***Total Choice Count*** $\tilde{x}_{\text{All}} = 60.7$	***Weighted Choice Score*** $\tilde{x}_{\text{All}} = 2.9$	***Average Choice per Opportunity*** $\tilde{x}_{\text{All}} = 0.05$
Chemical	**Univ. C = 15.5** $\tilde{x}_{\text{Chem}} = 0.0$	**Univ. F = 93.9** $\tilde{x}_{\text{Chem}} = 46.1$	**Univ. C = 17.8** $\tilde{x}_{\text{Chem}} = 1.9$	**Univ. B = 0.33** $\tilde{x}_{\text{Chem}} = 0.04$
Civil	**Univ. B = 18.5** $\tilde{x}_{\text{Civil}} = 0.7$	**Univ. H = 89.6** $\tilde{x}_{\text{Civil}} = 65.0$	**Univ. B = 19.3** $\tilde{x}_{\text{Civil}} = 2.5$	**Univ. B = 0.38** $\tilde{x}_{\text{Civil}} = 0.05$
Electrical	**Univ. D = 25.2** $\tilde{x}_{\text{Elect}} = 2.5$	**Univ. C = 118.2** $\tilde{x}_{\text{Elect}} = 69.4$	**Univ. D = 27.0** $\tilde{x}_{\text{Elect}} = 3.2$	**Univ. D = 0.36** $\tilde{x}_{\text{Elect}} = 0.06$
Mechanical	**Univ C. = 15.6** $\tilde{x}_{\text{Mech}} = 3.7$	**Univ. F = 108.3** $\tilde{x}_{\text{Mech}} = 47.7$	**Univ. C = 17.9** $\tilde{x}_{\text{Mech}} = 5.8$	**Univ. B = 0.29** $\tilde{x}_{\text{Mech}} = 0.12$

Choice and Quality

The five universities with the highest choice value engineering programs are coded as B, C, D, F and H for this study. These university aliases correspond to the same codes created for the universities from the previous study that quantified the course choice opportunity disparities between the engineering students in these degree programs and their non-engineering peers across campus (Forbes et al., 2015).

The specialized engineering degree programs in Table 3.10 move from delineating the *state* of course choice opportunity in undergraduate engineering programs in this country to what is *possible*. These exceptional programs demonstrate a compelling combination: top-ranked

ABET-accredited specialized engineering degree programs that also foster autonomy-supportive environments for their students in terms of course choice opportunity.

Looking across the four engineering disciplines, these maximum choice variable value programs offer students a median of 17 normalized credit hours of *free* electives, and grant students the opportunity to make *choices* in a median of over 100 normalized credit hours—over 75% of their total degree. These choice opportunities are both substantial and a deviation from the national trend of minimal course choice opportunity in engineering programs overall (Forbes et al., 2015) as well as the median choice variable values within the respective engineering disciplines.

Of the 16 maximum choice variable values listed in Table 3.10, it is worth noting that all are housed within just five universities. And, all are private institutions, with a Carnegie Classification of "Research University; very high research activity," where engineering makes up a significant portion of the undergraduate student body. Institution data for these five schools is presented in Table 3.11.

Table 3.11: Highest choice variable value universities: demonstrating comparatively more course choice opportunities for four engineering program-types.

Univ. Alias	Institution Size[1]	% Ugrad Pop. that is ENG[2]	# Accred. ENG Progs. at Univ.	*Total Free Elective Credit Hours* Maximum	*Total Choice Count* Maximum	*Weighted Choice Score* Maximum	*Ave. Choice per Opp.* Maximum
B	Medium	30	5	Civil		Civil	Chemical Civil Mechanical
C	Small	50	14	Chemical Mechanical	Electrical	Chemical Mechanical	
D	Small	35	6	Electrical		Electrical	Electrical
F	Medium	25	6		Chemical Mechanical		
H	Medium	45	3		Civil		

[1]"Small"refers to institutions with total undergraduate populations under 5,000 students; "Medium" refers to institutions with total undergraduate populations from 5,000 – 15,000 students (Collegedata, 2015)
[2]Rounded to the nearest 5%.

Two of the universities (B and C) have one or more of the highest variable values for three out of the four engineering program-types, a possible indicator that there is an overarching autonomy-supportive culture within their engineering colleges.

So clearly it is possible to offer students a reasonable amount of choice in their engineering curriculum within a highly-regarded, research-active institution. One might ponder why those institutions that do so tend to be both private and engineering-dominant campuses. And, noting their absence on the list, do the broad-based public universities that graduate the bulk of the nation's engineers do so within highly constrained programs that afford their students little choice or self-determination?

Comparing Course Choice Variable Values for Two University-Types

We have looked at the differences in course choice opportunities for engineering discipline programs from across the country, and established that the overall course choice opportunities tend to be the same (and bleak) for the studied chemical, civil, electrical, and mechanical engineering programs. Do differences exist in the course choice opportunities students experience in these disciplines if they are enrolled at different *types* of universities? Mann-Whitney U ($\alpha = 0.05$) statistical tests were used to look for significant differences between Doctoral and No Doctoral universities within each of the four engineering program-types for Total Free Elective Credit Hours, Total Choice Count, Weighted Choice Score, and Average Choice per Opportunity, respectively. Results indicated that for free electives, weighted choice, and Average Choice per Opportunity there are no statistically significant differences between the Doctoral and No Doctoral populations for any of the four engineering disciplines (see Appendix A). Regardless of university type, then, students within and across these disciplines tend to have the same—*minimal*—amount of free elective credit hours.

Results also indicated that for Total Choice Count statistically significant differences exist between the Doctoral and No Doctoral populations for civil engineering ($p = 0.030$), electrical engineering ($p = 0.004$), and mechanical engineering ($p = 0.007$) (Figure 5 and Table 12).

Figure 3.5: Total Choice Count for Doctoral versus No Doctoral universities across four engineering program-types.

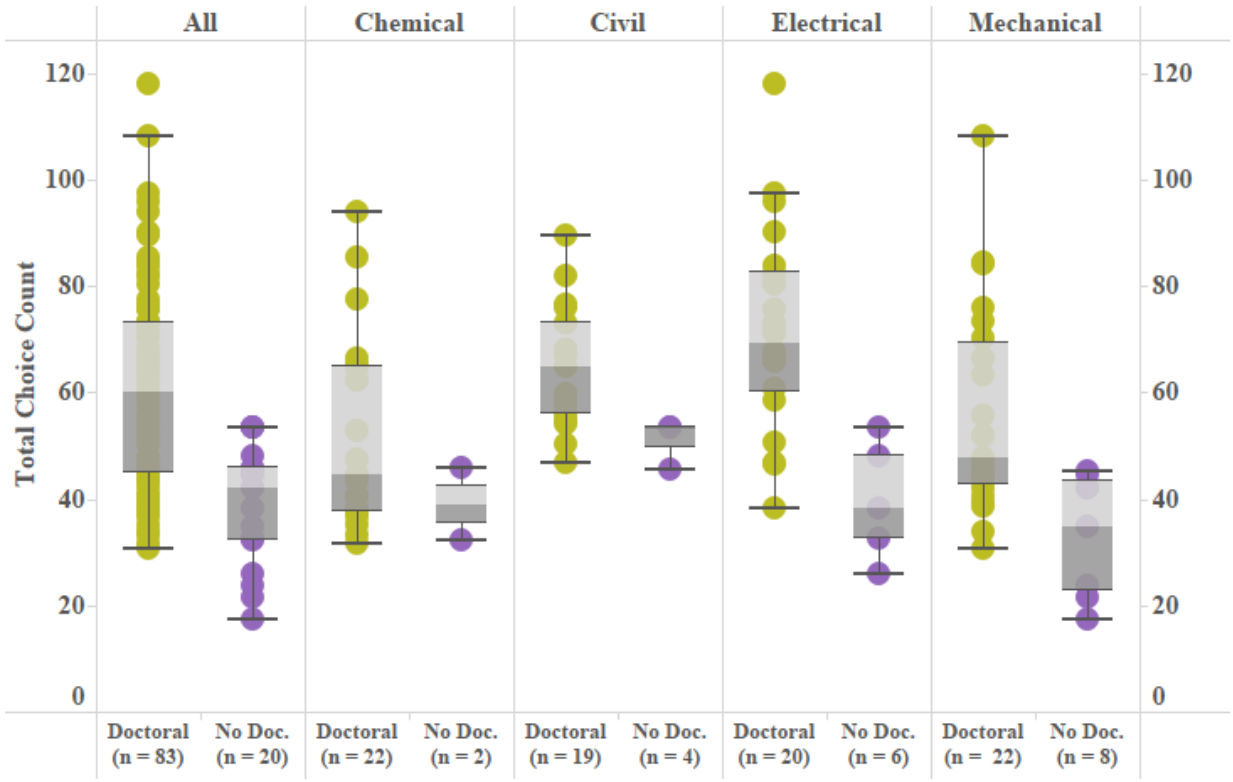


Table 3.12. Median Total Choice Count values and Mann-Whitney U p-values for Doctoral versus No Doctoral universities across four engineering program-types.

Engineering Program-Type				
All	**Chemical**	**Civil**	**Electrical**	**Mechanical**
$\tilde{x}_{\text{Doc}} = 60.3$	$\tilde{x}_{\text{Doc}} = 44.6$	$\tilde{x}_{\text{Doc}} = 65.0$	$\tilde{x}_{\text{Doc}} = 69.3$	$\tilde{x}_{\text{Doc}} = 47.7$
$\tilde{x}_{\text{No Doc}} = 42.1$	$\tilde{x}_{\text{No Doc}} = 39.0$	$\tilde{x}_{\text{No Doc}} = 53.6$	$\tilde{x}_{\text{No Doc}} = 38.2$	$\tilde{x}_{\text{No Doc}} = 34.8$
p = 0.000*	**p = 0.091**	**p = 0.030***	**p = 0.004***	**p = 0.007***

*Statistically significant p-value ($\alpha = 0.05$).

In each case (civil, electrical, and mechanical engineering) of statistically significant differences in Total Choice Count values between Doctoral and No Doctoral institutions, the Doctoral universities had larger Total Choice Count values and therefore offer engineering

students *more* opportunities to choose courses as they earn their undergraduate degrees. A likely contributing factor to this difference is that the Doctoral universities tend to be larger than the No Doctoral institutions, and thereby tend to have more course offerings within the university in general. For this study, the median full time total undergraduate populations rounded to the nearest 1000 were 12 times *larger* at Doctoral institutions versus No Doctoral institutions (24,000 versus 2,000) (ASEE Engineering College Profiles, 2013).

For the other three course choice variables (free electives, weighted, and Average Choice per Opportunity), no significant differences exist for these two categories of institutions. Again, these results indicate that the low course choice culture in engineering education extends across *disciplines* as well as across *university-types*. Though distinct programs and engineering colleges have been identified that are individually more autonomy-supportive in terms of course choice opportunity, no discernable patterns emerged from this study to indicate that increased course choice opportunity is more common within a certain discipline or university-type.

Comparing Choice Variable Values for 15 Universities Offering All Four Engineering Program-Types

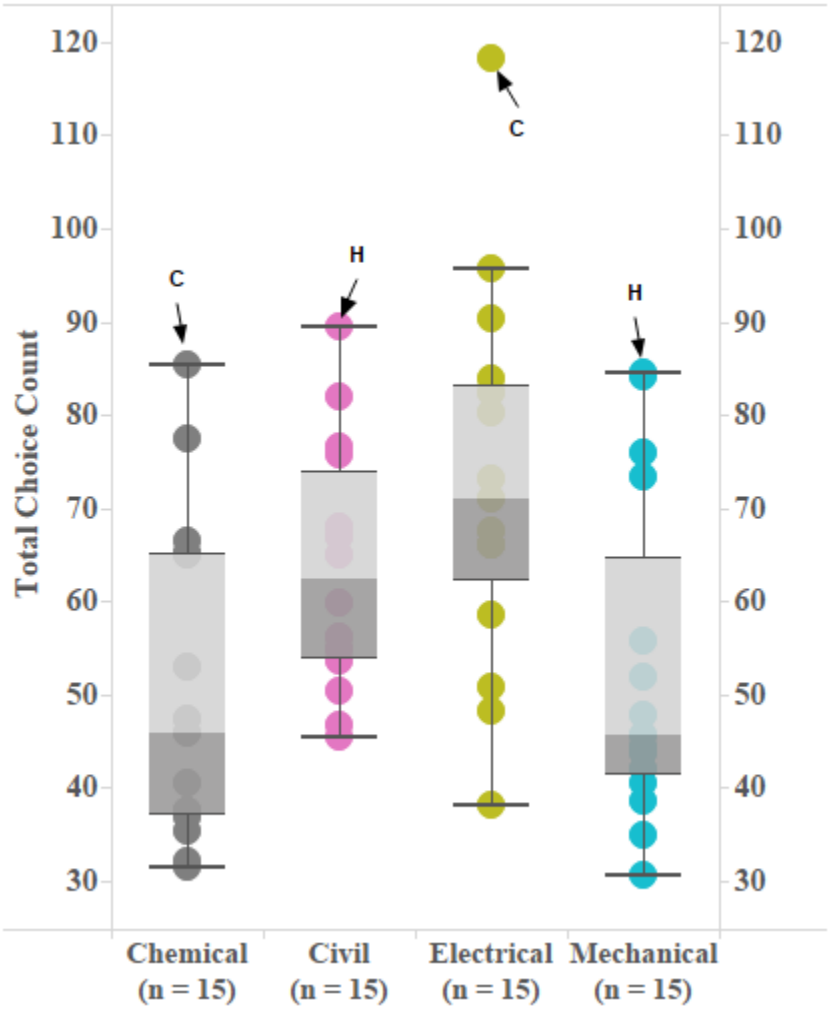
Fifteen of the 43 universities (34 Doctoral and 9 No Doctoral) with top-ranked engineering programs had top-ranked specialized engineering degree programs for *all* four engineering program-types included in this study (chemical, civil, electrical, and mechanical engineering) and therefore provide an opportunity to compare course choice opportunity across engineering specialties within universities. Three of the maximum choice variable value universities (B, C, and H) are included in these 15 universities.

The Friedman Analysis of Variance (ANOVA), a nonparametric test for more than two dependent groups of ordinal data, was used to test for differences between the four engineering

program-types across these 15 universities. Results indicate that no statistically significant differences exist for free electives ($p = 0.326$) or Average Choice per Opportunity ($p = 0.627$) within these universities between their chemical, civil, electrical, and mechanical engineering programs. In other words, at these 15 universities, students enrolled in these four types of engineering degree programs are generally afforded equivalent free elective opportunities as one another and generally experience comparable magnitudes of choice for the course choice opportunities they encounter.

Results from the Friedman ANOVA also indicate that statistically significant differences exist for total choice ($p = 0.000$) and weighted choice ($p = 0.048$). See Figures 3.6 and 3.7 and Tables 3.13 and 3.14.

Figure 3.6: Total Choice Count values for four engineering program-types offered at 15 universities.



Note: Labels C and H identify the highest choice variable value standout universities. See Tables 3.10 and 3.11.

Table 3.13: Median Total Choice Count values and Friedman ANOVA p-value for four engineering program-types offered at 15 universities

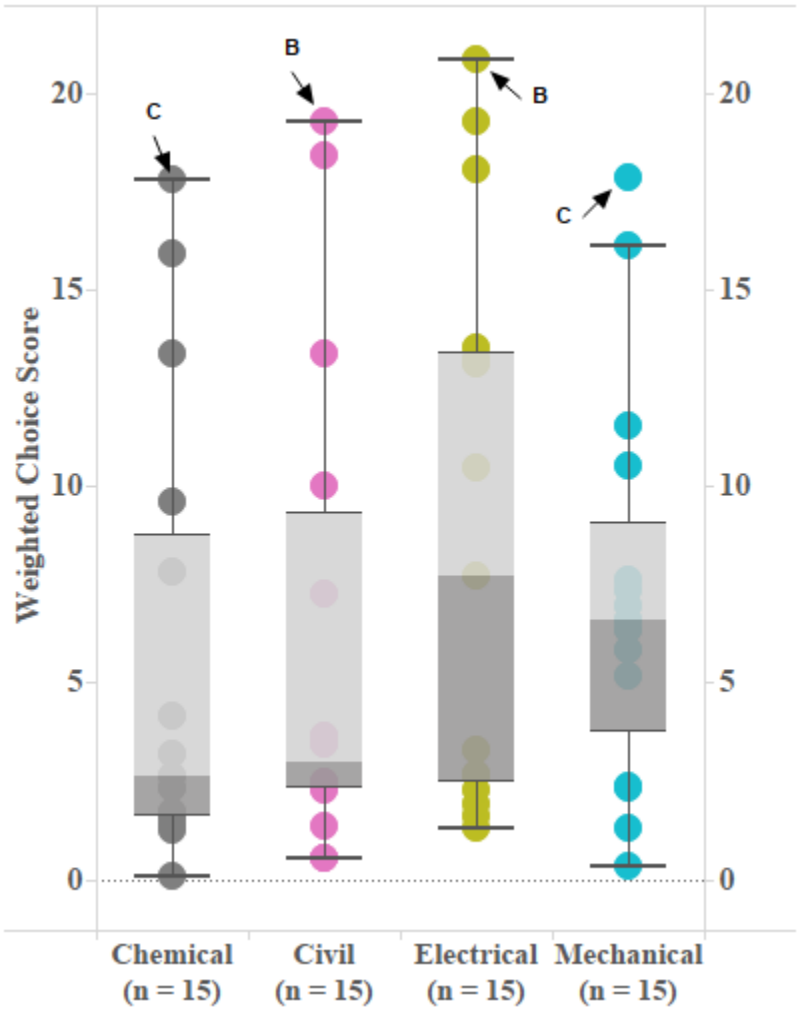
Engineering Program-Type				Friedman ANOVA
Chemical	**Civil**	**Electrical**	**Mechanical**	
$\tilde{x}_{Chem} = 45.9$	$\tilde{x}_{Civil} = 62.5$	$\tilde{x}_{Elect} = 71.1$	$\tilde{x}_{Mech} = 45.7$	**p = 0.000***

*Statistically significant p-value ($\alpha = 0.05$).

The Wilcoxon Signed Rank test ($\alpha = 0.05$) was used for the post hoc analysis to determine which engineering program-types have statistically significant differences in Total Choice Count values within universities. For this population of universities: 1) there is no statistically significant difference between chemical and mechanical engineering total choice ($p = 0.280$); 2) chemical and mechanical engineering have less total choice than civil and electrical engineering; and 3) there is no statistically significant difference between civil and electrical engineering total choice ($p = 0.050$).

To summarize, at universities that offer chemical, civil, electrical, and mechanical engineering degree programs, students enrolled in chemical and mechanical engineering degree programs tend to get fewer total course choice opportunities than their peers in civil and electrical engineering degree programs.

Figure 3.7: Weighted Choice Scores for four engineering program-types offered at 15 universities.



Note: Labels B and C identify the highest choice variable value standout universities. See Tables 3.10 and 3.11.

Table 3.14: Median Weighted Choice Scores and Friedman ANOVA p-value for four engineering program-types offered at 15 universities

Engineering Program-Type				Friedman ANOVA
Chemical	**Civil**	**Electrical**	**Mechanical**	
$\tilde{x}_{Chem} = 2.7$	$\tilde{x}_{Civil} = 3.0$	$\tilde{x}_{Elect} = 7.7$	$\tilde{x}_{Mech} = 6.6$	**p = 0.048***

*Statistically significant p-value ($\alpha = 0.05$).

Again, the Wilcoxon Signed Rank test ($\alpha = 0.05$) was used for the post hoc analysis to determine which engineering program-types have statistically significant differences in Weighted Choice Scores within universities. For this population of universities: 1) there is no statistically significant difference between chemical, civil, and mechanical engineering weighted choice; 2) there is no statistically significant difference between mechanical and electrical engineering weighted choice ($p = 0.191$); and 3) there *is* a statistically significant difference between the weighted choice for chemical and civil engineering and the weighted choice for electrical engineering, with lower Weighted Choice Scores for chemical and civil engineering than for electrical engineering.

In other words, at universities that offer chemical, civil, electrical, and mechanical engineering degree programs, students enrolled in chemical and civil engineering degree programs tend to get *less* overall choice magnitude than their peers in electrical engineering. The choice variable data from these 15 universities suggest that engineering degree programs within the same university tend to offer students the same amount of free electives but are likely to differ with respect to the total number of course choice opportunities they offer students. These findings may suggest that the number of free electives offered by engineering degree programs within a university is influenced by the culture of the engineering school at large, and the extent to which that culture is autonomy-supportive of students with respect to course choice opportunity. For example, one university from this population offers students across all four engineering program-types 16 credit hours of free electives, while none of the students in the four engineering program-types at three of the other universities get to choose any free electives. Additionally, these findings may indicate that the total number of course choice opportunities offered to students across engineering disciplines within a university is conversely more

influenced by individual department culture, and therefore more subject to variations. For engineering educators motivated to encourage change, these findings could mean that opportunities to create more autonomy-supportive cultures in engineering degree programs exist at the departmental and engineering college-wide institutional levels.

Discussion, Conclusions, Future Work

This study explored the course choice opportunities afforded to undergraduate students pursuing engineering degrees in the top-ranked chemical, civil, electrical, and mechanical engineering programs across the country. Findings from this study suggest that course choice opportunity for undergraduate students across these disciplines is commonly bleak, and a low course choice opportunity *culture* is prevalent. Previous work establishing autonomy as a basic human psychological need (Deci et al., 1991; Ryan and Deci, 2000) makes it logical to hypothesize that this low choice culture throughout engineering disciplines is in conflict with students' psychological need to feel a sense of volition in their acts, and therefore is likely to have detrimental effects for students endeavoring to matriculate through engineering. Does this low level of choice play a role in engineering's notoriously low in-migration (Ohland et al., 2008)? Does it play a role in who chooses an engineering pathway to begin with?

Students enrolled in these engineering disciplines are frequently afforded just one opportunity to choose a course of their liking over the course of their entire undergraduate study, with others getting no such opportunities at all. These findings translate to a typical student arriving to his or her college campus at just ~18 years of age expected to emerge from an engineering program four-plus years later foregoing any opportunities to pick a free elective, not to mention study abroad or experience many of the other academic exploration opportunities

readily available to their non-engineering peers (lest they extend their degree, often at a great expense). This convention not only seems unfair to students and unrealistic to ask of them, this study shows it is *unnecessary* to meet accreditation expectations. And, surely a "one size fits all" approach to curricular design limits students' individual exploration, and resulting creativity.

This study outlined both the mainstream state of course choice opportunity in chemical, civil, electrical, and mechanical undergraduate engineering programs in this country as well as what exceptional programs within each specialization are demonstrating is *possible*. Standout programs clearly exist within each engineering discipline that offer students considerably more choice for each of the choice metrics developed for this study.

The highest choice variable value programs offer students a median of more than five free elective courses, a substantial deviation from the national trend of minimal course choice opportunity in engineering programs overall (Forbes, Bielefeldt, and Sullivan, 2015; Forbes et al., 2015) as well as the median choice variable values within the respective engineering disciplines. These standout programs demonstrate similar possibilities for improvement across each of the course choice metrics.

These standout programs show that—although exceptions—ABET-accredited top-ranked specialized engineering degree programs within highly research active engineering colleges *do* exist that foster autonomy-supportive environments for their students in terms of comparatively high course choice opportunity. The standout programs with the highest course choice variable values demonstrate tangible possibilities for re-structuring the design of undergraduate engineering degree programs to better support students' need for autonomy by way of increased course choice opportunities. One obvious beneficial outcome to this restructuring could be improvement to the notoriously poor in-migration of students in engineering (Ohland et al.,

2008) and lowered out-migration of successful students seeking more personal choice in the design of their education. Programs with more choice and flexibility may be more accommodating of students transferring in without losing time to graduation; this is important given that engineering programs do not differ substantially from their cross-campus counterparts in retention of students but rather in the migration of students *into* the major as compared to non-engineering disciplines (Ohland et al., 2008).

An overhauling of engineering education is needed, taking into account the psychological and developmental needs of students in concert with a foundation of ethical, demanding, effective, and reputable engineering education. This process necessitates a willingness to stretch beyond the nature of many current interventions aimed at improving engineering enrollments and retention, such as community-building, cognitive development, or occupation-choice interventions, that work to address these challenges by changing the *students* (Watson and Froyd, 2007) and expand towards a holistic approach of thoughtfully sculpting engineering education as a whole to better support students and their basic needs.

Lasting, systemic change will require engineering education to reinvent itself (Institute of Medicine, National Academy of Engineering, and National Academy of Sciences, 2010), a process that calls for engineering educators to apply the very principles of the engineering design process to undergraduate engineering education itself—iterating the design until it is optimized to attract and effectively educate more (and more diverse) engineers in concert with personal fulfillment. This process demands thinking critically and creatively about undergraduate engineering degree programs from the perspective of the *students*—both those currently enrolled and those we hope to attract in the future. This study provides a starting point via concrete means and aspirational target values for engineering educators motivated to stimulate change in low

course choice opportunity programs, and contribute towards a collective autonomy-supportive culture in undergraduate engineering education.

CHAPTER 4

DIVERGENT REQUIREMENTS FOR TECHNICAL AND NON-TECHNICAL COURSEWORK IN UNDERGRADUATE ENGINEERING EDUCATION

Abstract

For complex problem solving, engineers benefit from the divergent thinking skills highly developed among humanities students *and* the convergent thinking skills more developed among engineering students. Undergraduate engineering education faces pressures to add both technical and non-technical content, while simultaneously facing pressures to decrease total credit hours, educational costs, and time to degree. This study examined the distribution of technical versus non-technical coursework for 103 US News & World Report top-ranked and ABET-accredited specialized undergraduate degree programs in chemical, civil, electrical, and mechanical engineering. The work serves as a touch point for capturing how today's discipline-based engineering degree programs distribute required coursework between technical and non-technical areas of study to educate engineers, and an opportunity to deliberately envisage where the field might go from here. For this study, *technical* was defined as coursework in engineering, math or natural science and *non-technical* was defined as coursework outside of engineering, math and natural science. Findings reveal a wide range of required technical credit hours for these four commonly-encountered discipline-based engineering programs, ranging from 62% to 86% (median 75%) of the total degree. The sometimes immense fluctuations in credit hour requirements (across universities and across engineering programs within the same college) suggest that consensus does not exist amongst engineering educators regarding the appropriate allocation of technical versus non-technical coursework for an undergraduate engineering education, and there are substantially divergent interpretations of what constitutes adequate "general education" for an engineer.

Background

The recognition that the work of engineers encompasses the humanities dates back to the 1800's (Rojter, 2004). Today, general agreement exists that engineers need considerable understanding of subject matter traditionally thought of as humanities in order to serve effectively and responsibly as professionals (Hynes and Swenson 2013; NAE 2004, 2005; Rojter, 2004; Russell, Stouffer, and Walesh, 2000; Sharma, 2013; Sherk, 2007; Sjursen, 2007). After all, "technical problems frequently are also social, ethical, political, and international problems," (Shert, 2007) and the nature of solutions to these complex problems and the technological design and development they entail are inescapably rooted in *values* with philosophical and spiritual underpinnings (Luegenbiehl and Dekker 1987). Systems-thinking is needed to tackle the complex, interdependent, oftentimes multidisciplinary problems that engineers encounter in the workforce, and given the changing professional landscape in which engineers work, engineers increasingly benefit from "dynamism, agility, resilience, and flexibility" (NAE, 2004).

It has been recommended that engineering education reinvent itself (Institute of Medicine, NAE, and NAS, 2010; NAE, 2005) for a society best served by a nimble, culturally competent (Chubin, May, and Babco, 2005) broadly-educated engineer (NAE, 2005). Current models of engineering education are "losing the battle for the imaginations of young people," and are seeped in a "seemingly endless drudgery of courses that appear to be largely disconnected, not only from [student] interests, but also from the broader picture of what engineering could be, and should be, about" (Kalonji, 2005).

Humanities and social sciences courses within engineering programs (commonly referred to as "general education") need to be flexible yet coherent (Blewett, 1993), emblematic of

engineering as a diverse profession that benefits from diverse skillsets (Sharma, 2013). For complex problem solving, engineers need the divergent thinking skills highly developed among humanities students *and* the convergent thinking skills more developed among engineering students (Hudson, 1975). Yet, engineering education faces pressures to add both technical and non-technical content, amidst rapidly changing technologies and the "growing requirement for engineers to be able to make responsible, cultural, political and social decisions that shape the future of the world" (Sjursen, 2007 p. 135), while simultaneously facing pressures to decrease total credit hours (Bucknam, 1998; Russell, Stouffer, and Walesh, 2000), educational costs and time to degree.

At the turn of this century, the Accreditation Board for Engineering and Technology (ABET) expanded the possibilities for undergraduate engineering with the move to outcomes-based accreditation under the Engineering Criteria 2000 (EC 2000). ABET requires that today's accredited undergraduate engineering programs meet a general criteria that, among other requirements, includes (out of a four-year degree): one year of college-level math and basic sciences, one and one-half years of engineering, and a "general education component that complements the technical content of the curriculum and is consistent with the program and institution objectives" (ABET, 2015). This represents a change from the previous requirements which specified a minimum of one-half year of humanities and social science. Within this general framework, programs are granted the flexibility to meet ABET's outcomes criteria in potentially diverse ways with especially great room for interpretation of the general education component. Thus, with intentionality, engineering degree programs now have freedom to reflect their values in the curricular choices made available to their students.

The National Academy of Engineers recommends that undergraduate engineering programs introduce interdisciplinary learning and "more vigorously exploit the flexibility inherent in the outcomes-based accreditation approach to experiment with novel approaches for baccalaureate education" (NAE, 2005). ABET has given engineering educators the power to take on this change internally rather than to force it externally, but despite this opportunity and recommendations to the contrary, it is hypothesized that the predominant focus on technical content knowledge remains widespread in engineering education. If it is, we are paying a high price, as students with broader non-technical interests get filtered out (Vanasupa, 2009) or self-select to study non-engineering disciplines. With the year 2020 fast approaching, this study serves as a touch point for capturing how discipline-based engineering degree programs in this outcomes-based accreditation era are distributing required coursework between technical and non-technical areas of study to educate engineers, and provides an opportunity lens to envisage where the field might go from here.

Research Questions

- What is the extent of *technical* coursework required of undergraduate engineering students enrolled in the nation's top-ranked chemical, civil, electrical, and mechanical engineering degree programs?
- How do the technical coursework requirements in these undergraduate engineering degree programs compare to those in math and natural science degree programs?
- What is the extent of *non-technical* coursework required of undergraduate engineering students enrolled in the nation's top-ranked chemical, civil, electrical, and mechanical engineering degree programs? Do elective opportunities exist for students to take additional non-technical courses should they so choose?

- Based on the studied population, does consensus exist regarding the appropriate balance of courses between technical and non-technical areas to effectively educate a specialized engineer at the undergraduate level?

Methods

This study examines the distribution of technical versus non-technical coursework for 103 top-ranked (by US News & World Report, 2015), ABET-accredited undergraduate programs in chemical, civil, electrical, and mechanical engineering. University data for the 43 universities that house these 103 degree programs are provided in Table 4.1.

Table 4.1: Full time undergraduate population data for 43 universities with top-ranked engineering specialty degree programs.

Full Time U-grad Pop. (rounded to nearest 1000)	N	% Full Time U-grad Pop. that is ENG	N	# of ABET-accredited Engineering Degree Programs at University	N
0 – 1,000	4	0 – 10	2	1 – 3	3
2,000 – 5,000	8	11 – 20	20	4 – 6	11
6,000 – 10,000	6	21 – 30	10	7 – 9	6
11,000 – 20,000	7	31 – 40	2	10 – 12	14
21,000 – 30,000	11	41 – 50	3	13 – 15	6
31,000 +	7	51+	6	16 – 17	3

Thirty-four of the 43 universities offer doctorates as the highest degree and are classified by Carnegie (Carnegie Classification of Institutions of Higher Learning, 2015) as “Research Universities (very high research activity)” (RU/VH). These universities are referred to as “Doctoral” throughout this chapter. The remaining nine universities do not offer doctorate

programs and are generally smaller in terms of undergraduate population. These universities are referred to as "No Doctoral" throughout this chapter.

Of the 103 total degree programs included in this study, 24 are in chemical engineering; 23 in civil engineering; 26 in electrical engineering; and 30 in mechanical engineering, with varying sample sizes due to ties in the rankings as well as the unequal number of ranked programs across engineering program-types for No Doctoral universities. To provide comparisons for the technical and non-technical course balance in engineering programs, math, chemistry, and physics degree programs housed in the same 43 universities as the 103 engineering programs of interest were also studied.

For the studied degree programs, technical and non-technical course data was taken from the university 2013-2014 online catalog. In order to delineate technical versus non-technical course distribution, the following information was gathered from the catalog for each degree program: the total required technical credit hours ("technical"), the total required non-technical credit hours ("non-technical"), the total *possible* non-technical credit hours ("possible non-technical"), and the total credit hours required for the degree. Possible non-technical credit hours include required non-technical credit hours plus any additional free elective credit hours for which a student could choose non-technical courses if he or she was so inclined.

Here, *technical* was defined as coursework in engineering, math or natural science and *non-technical* was defined as any coursework outside of engineering, math or natural science. Though it would be informative to do so, engineering credit hour requirements were not counted separately from math and natural science requirements because of the impossibility of uniformly and correctly categorizing courses as engineering versus natural science or math using information only available in a university catalog. Because of ABET's outcomes-based

approach, it is possible to include both engineering *and* science or math topics within the same course, confounding its categorization. Hence, math, natural science and engineering courses are grouped into one category and referred to as "technical" courses.

Data from this study were normalized to 130 total degree credit hours as a continuation of the methods established by previous studies that utilized this dataset (Forbes, Bielefeldt, and Sullivan, 2015; Forbes et al., 2015, 2015). For example, a three credit hour required calculus course as part of a 120 credit hour civil engineering degree program would be counted as *technical* credit hours and normalized to 3.3 credit hours as part of a 130 credit hour degree program (3 * (130 / 120) = 3.3). Remembering that ABET requires all accredited programs to have a minimum of one year of math and basic science and one and one half-years of engineering, this translates to 32.5 credit hours of math and natural science and 48.8 credit hours of engineering, totaling a minimum ABET requirement of 81.3 technical credit hours within a 130 credit hour degree program.

The collected data were compiled in Microsoft Excel 2013. All of the data for this study were based on credit hour and course counts and are therefore ordinal in nature. As such, nonparametric tests were employed for all statistical analyses. Kruskal-Wallis tests (a nonparametric test analogous to the one-way Analysis of Variance, ANOVA) were used to look for statistically significant differences between independent samples for > 2 groups, and the Friedman ANOVA was used in cases where the data across the > 2 groups was dependent (i.e. from the same university). Mann-Whitney U tests (a nonparametric test analogous to the t-test) was used to look for statistically significant differences in situations where there were two groups of independent data. The Wilcoxon Signed Rank test was instead used to look for

statistically significant differences in cases where there were two groups of dependent data (i.e. within the same degree program).

Friedman ANOVA and Spearman Rank Correlation analyses were conducted using The Statistical Package for the Social Sciences (SPSS) 23. All other statistical analyses were performed using MVPstats, and in all cases were two-tailed with significance levels of $\alpha = 0.05$, with the exception of the Spearman's Rank Correlation analysis which used a significance level of $\alpha = 0.01$ to draw attention to the most significant correlations.

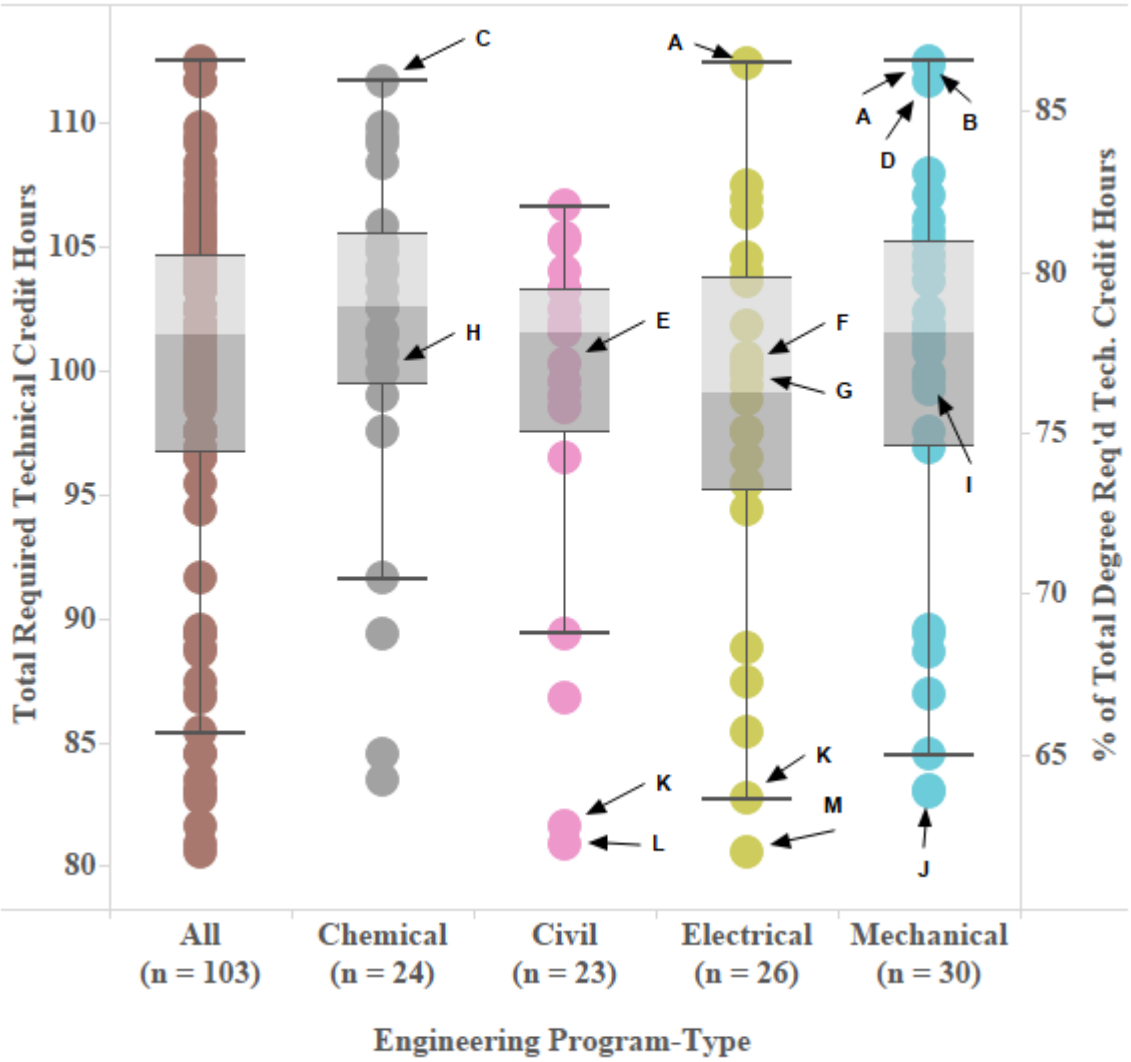
Results

Results for the technical versus nontechnical credit hour counts for the 103 top-ranked programs across chemical, civil, electrical, and mechanical engineering are presented in Figures 4.1 – 4.3 and Tables 4.2 – 4.4.

Total Required Technical Credit Hours

The total number of required technical credit hours across the four engineering specialties are presented in Figure 4.1 and Table 4.2. Each data point represents an individual degree program, with the overlaid box and whisker plot showing the median, upper and lower quartile values for all of degree programs within each discipline. As an example, the 24 studied chemical engineering degree programs required a median of 103 technical credit hours, with the lowest technical requirement of 83 credit hours and the highest technical requirement of 112 credit hours (see Figure 4.1).

Figure 4.1: Total required technical credit hours by university for four engineering program-types.



Note: Labels A through M identify degree programs with the highest, lowest, and 100 (approximately median) total required technical credit hours. See Table 4.5 for corresponding university data.

Table 4.2. Median values of total required technical credit hours for four engineering program-types.

Engineering Program-Type					Kruskal-Wallis
All	**Chemical**	**Civil**	**Electrical**	**Mechanical**	
$\tilde{x}_{All}$ = 101.4 (n = 103)	$\tilde{x}_{Chem}$ = 102.6 (n = 24)	$\tilde{x}_{Civil}$ = 101.6 (n = 23)	$\tilde{x}_{Elec}$ = 99.1 (n = 26)	$\tilde{x}_{Mech}$ = 101.6 (n = 30)	**p = 0.270**

Median total required technical credit hour values for each of the four engineering program-types was approximately 100, which comprises just over 75% of a normalized 130 credit hour degree program. The spread of data points within each engineering discipline indicates a wide *range* of technical requirements amidst this population of specialized programs, with the highest technical requirements at ~112 credit hours and the lowest requirements at ~81 credit hours (ABET's minimum requirement) of technical content. Comparing the highest versus lowest technical requirements, then, we see a difference of a whopping *31 credit hours*—approximately 10 three credit-hour courses. Thinking in terms of a normalized 130 credit hour degree, this is almost an entire *year* during which some students would exclusively take technical courses while their counterparts in other programs might take *none*, but all would graduate with a top-ranked, ABET-accredited, specialized engineering degree.

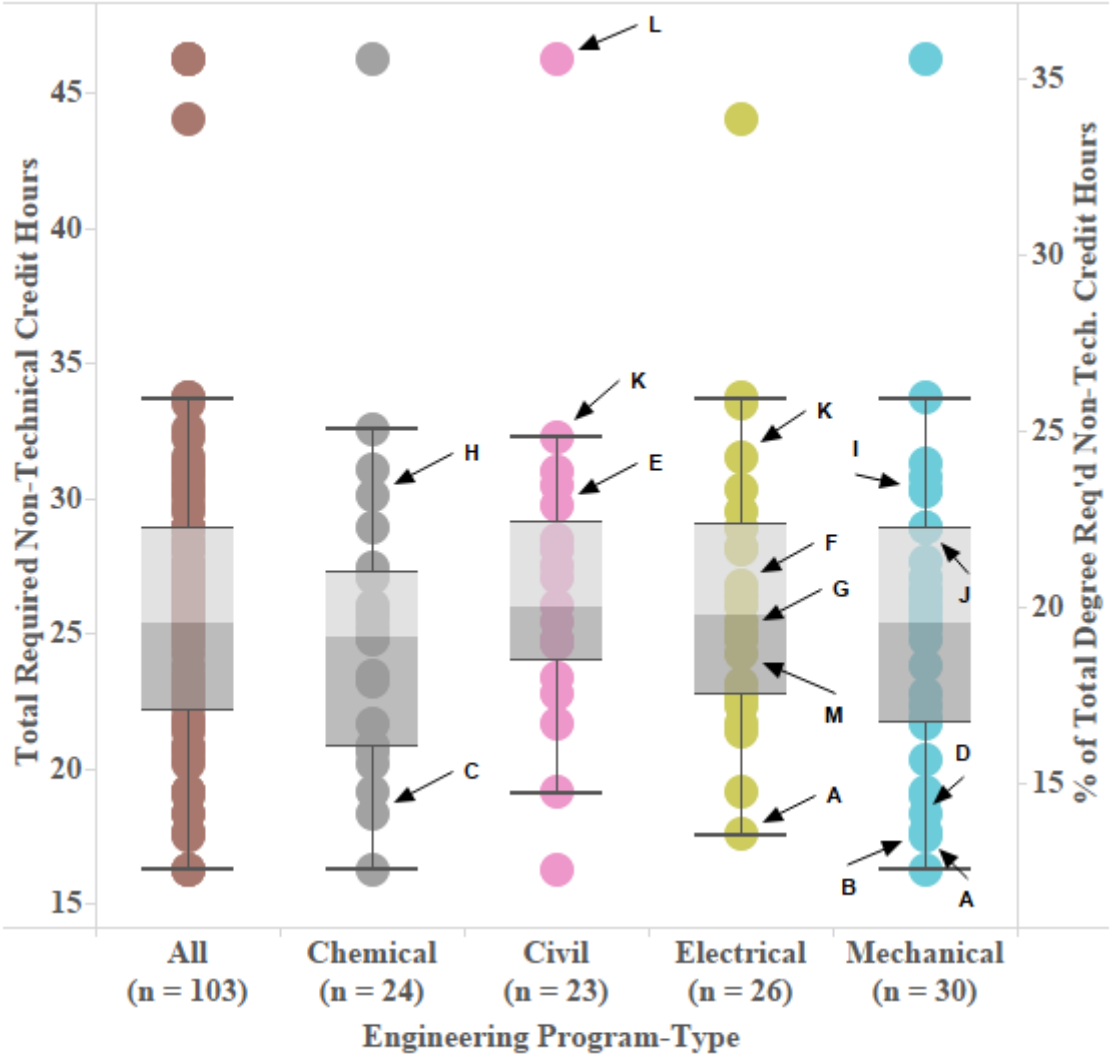
This immense fluctuation in technical requirements suggests that consensus does not exist amongst engineering educators regarding the appropriate balance of coursework for an undergraduate engineering education. Technical versus non-technical course distributions for five programs with the highest, lowest, and approximately median total required technical credit hours, respectively, will be highlighted in a later section of this chapter.

Results of a Kruskal-Wallis nonparametric test revealed that there is no statistically significant difference in the total required technical credit hours for this population of chemical, civil, electrical, and mechanical engineering degree programs, suggesting that these engineering disciplines tend to require an equivalent amount of technical courses as one another.

Total Required Non-Technical Credit Hours

The total required non-technical credit hours across the four engineering specialties are presented in Figure 4.2 and Table 4.3.

Figure 4.2: Total required non-technical credit hours by university for four engineering program-types.



Note: Labels A through M identify degree programs with the highest, lowest, and 100 (approximately median) total required technical credit hours. See Table 4.5 for corresponding university data.

Table 4.3. Median values of total required non-technical credit hours for four engineering program-types.

Engineering Program-Type					Kruskal-Wallis
All	Chemical	Civil	Electrical	Mechanical	
$\tilde{x}_{All}$ = 25.4 (n = 103)	$\tilde{x}_{Chem}$ = 24.9 (n = 24)	$\tilde{x}_{Civil}$ = 26.0 (n = 23)	$\tilde{x}_{Elec}$ = 25.7 (n = 26)	$\tilde{x}_{Mech}$ = 25.4 (n = 30)	**p = 0.633**

Median required non-technical credit hours for each of the four engineering program-types was approximately 25 credit hours, comprising roughly 19% of a normalized 130 credit hour degree program. Similar to the technical requirements discussed previously, a wide range exists in the number of non-technical requirements among these specialized programs, with the highest requirements at 46 credit hours for three programs and the lowest at just over 16 credit hours for another three programs. Mirroring the differentials in technical requirements, this spread between the highest and lowest non-technical requirements is equivalent to almost an entire year during which some students might take *only* non-technical courses while others take *none* at all, indicative of substantially divergent interpretations of what constitutes the essential "general education" (ABET, 2015) for the education of an engineer. Whether this divergence is a reflection of the intentional values and educational philosophy of an institution, or a curriculum that grew organically over time, is worthy of reflection. At any rate, the divergence demonstrates what is possible within a highly regarded engineering program with respect to nontechnical content.

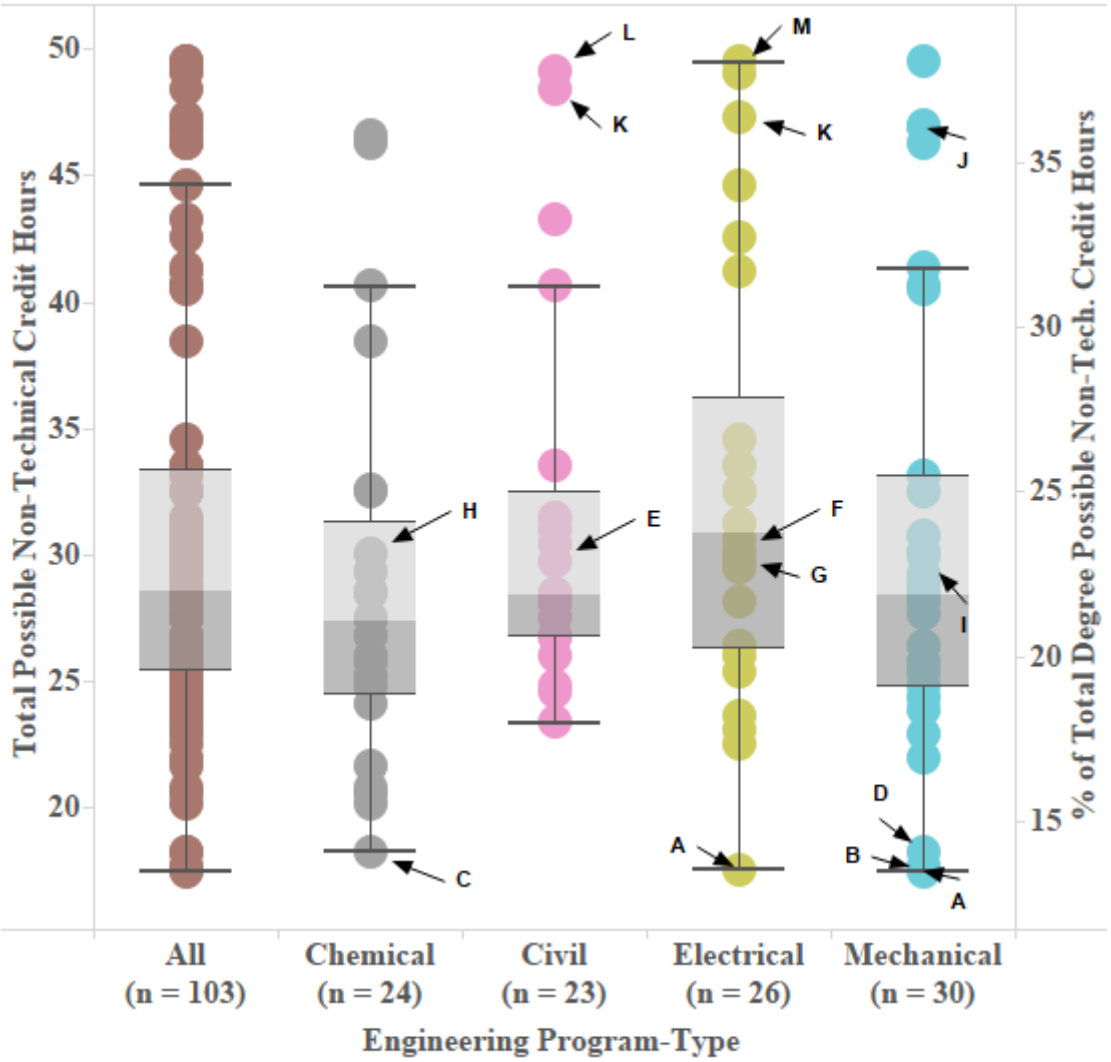
Results of a Kruskal-Wallis test confirmed that there is no statistically significant difference in the total required non-technical credit hours for this population of chemical, civil, electrical, and mechanical engineering degree programs. Again, like the technical requirements, these results suggests that these engineering specialties tend to require an equivalent amount of non-technical courses as one another.

Total Possible Non-Technical Credit Hours

The total *possible* non-technical credit hours across the four engineering specialties are presented in Figure 4.3 and Table 4.4. Possible non-technical credit hours include required non-technical

credit hours plus any additional free elective credit hours for which a student can take non-technical courses if he or she is so inclined.

Figure 4.3: Total possible non-technical credit hours by university for four engineering program-types.



Note: Labels A through M identify degree programs with the highest, lowest, and 100 (approximately median) total required technical credit hours. See Table 4.5 for corresponding university data.

Table 4.4. Median values of total possible non-technical credit hours for four engineering program-types.

Engineering Program-Type					Kruskal-Wallis
All	**Chemical**	**Civil**	**Electrical**	**Mechanical**	
$\tilde{x}_{All}$ = 28.6 (n = 103)	$\tilde{x}_{Chem}$ = 27.4 (n = 24)	$\tilde{x}_{Civil}$ = 28.4 (n = 23)	$\tilde{x}_{Elec}$ = 30.9 (n = 26)	$\tilde{x}_{Mech}$ = 28.4 (n = 30)	**p = 0.265**

Possible non-technical credits are quite similar to the required non-technical values (a median of 29 credits versus 25 credits, respectively, across all 103 degree programs), symptomatic of the culture of making few free electives available to students that is commonplace today, in 2015, in undergraduate engineering (Forbes, Bielefeldt, and Sullivan, 2015; Forbes et al., 2015, 2015).

Kruskal-Wallis tests show that there is no statistically significant difference in the possible non-technical credit hours across engineering disciplines, an indicator that students across these programs tend to get comparable, limited opportunities to choose non-technical coursework.

Course Distribution for Programs with High, Low, and Median Technical Requirements

Leaving behind the collective exploration of technical versus non-technical requirements over the 103 degree programs, it is instructive to look within a subset of selected degree programs that represent the five highest, five lowest, and approximately five median total required technical credit hours to gain an understanding of the how technical versus non-technical coursework is balanced across a range of individual programs (Table 4.5).

Table 4.5: Curricular balance and university data for degree programs with the highest, lowest, and 100 (approximately median) total required technical credit hours.

Univ. Alias	Carnegie Class.[1]	Inst. Type	% Ugrad Pop. that is ENG[2]	Eng. Program Type	Total Req'd Tech. Credit Hours	Total Req'd Non-Tech. Credit Hours	Total Possible Non-Tech. Credit Hours
Highest Required Technical Credit Hours							
A	RU/VH	Public	11	Mech.	113	17	17
A	RU/VH	Public	11	Elect.	112	18	18
B	RU/VH	Public	11	Mech	112	18	18
C	RU/VH	Public	15	Chem.	112	18	18
D	Master's L	Public	7	Mech.	112	18	18
100 Required Technical Credit Hours							
E	RU/VH	Private	23	Civil	100	30	30
F	RU/VH	Private	12	Elect.	100	27	30
G	Spec/Engg	Private	91	Elect.	100	25	30
H	RU/VH	Public	13	Chem.	100	30	30
I	Spec/Engg	Private	97	Mech.	100	30	30
Lowest Required Technical Credit Hours							
J	RU/VH	Private	24	Mech.	83	29	47
K	RU/VH	Private	51	Elect.	83	32	47
K	RU/VH	Private	51	Civil	82	32	48
L	RU/VH	Private	45	Civil	81	46	49
M	RU/VH	Private	34	Elect.	81	24	49

[1] Master's L = "Master's Colleges and Universities (larger programs)"; RU/VH = "Research Universities (very high research activity)"; Spec/Engg = "Special Focus Institutions--Schools of engineering"
[2] Rounded to the nearest 5%.

The five programs with the *highest* technical count each require students to take 112 or 113 credit hours of technical courses, representing ~86% of their coursework. These students get no free electives and all take approximately six, three credit-hour courses in humanities for their "general education." These programs are all at public institutions where engineering makes up a fairly small percentage (7-15%) of the undergraduate study body, and therefore engineering

students likely notice a large contrast in their educational experience compared to peers in non-engineering disciplines. For example, at Institution A peers earning B.S. degrees in chemistry, mathematics, and physics have 78%, 59%, and 41% required technical coursework within their degrees while engineering students have 87%. Thus students who are interested in STEM but desire more curricular balance and breadth in their college experience may migrate to those non-engineering STEM majors.

On the opposite end of the spectrum, the five programs with the *lowest* technical count require students to take only 81-83 credits of technical electives (at or just above ABET's minimum requirement for math, science, and engineering coursework), representing just ~63% of their coursework. These are all highly regarded private institutions where engineering students comprise a larger portion (24-51%) of the undergraduate student body. Non-technical credit hour requirements vary substantially across these five degree programs, but each requires at least 24 credits of non-technical coursework (and one almost double that at 46 credits).

The highest non-technical requirement is 46 credit hours—two and a half times more non-technical coursework than is found among the ~18 non-technical credit hours required by the five degree programs with the highest technical requirements.

The degree programs with the highest non-technical requirements also vary greatly in their allocation of *free electives* that could be used for either technical or non-technical courses, and range from 3 to 25 credit hours. Thus, technical coursework for these programs could increase to 65-82% of the degree, at the discretion of the student.

At the institutions requiring the fewest technical credits, more similarly was found between the amount of required technical coursework in the engineering degrees and other related STEM fields; as an example, at institution K the B.S. degrees in chemistry, mathematics,

and physics require 59-63% technical courses, compared to just over 63% for B.S. degrees in civil and electrical engineering.

The mid-range group requires students to take 100 credit hours of technical electives (77% of degree program) and 25 – 30 credit hours of non-technical coursework. Three of these engineering degree programs offer students *zero* free electives, while two offer students 3 or 5 credit hours of electives that they can put towards technical or non-technical coursework. This group represents a broad range of institutional characteristics.

It is evident from these data that consensus does not exist amongst top-ranked, discipline-specific engineering programs on the essential distribution of technical versus non-technical coursework in order to properly prepare an engineering graduate. It is also clear that curricular choice is not a factor in the ranking of engineering degree programs by US News & World Report, as each program included in this study is top-ranked and highly-regarded.

Engineering students enrolled across these degree programs are certain to have disparate academic experiences and are sure to graduate with divergent skillsets. While graduating engineers with a wide range of skills can be advantageous to meet the complex and evolving needs of society, this result is unsettling if it is a result of inadvertent curriculum choices vs curriculum *designed with the end in mind.*

Comparing Technical and Non-Technical Credit Hour Requirements for 15 Universities Offering All Four Engineering Program-Types

Fifteen of the universities in this study had top-ranked specialized engineering degree programs in all four disciplines (chemical, civil, electrical, and mechanical engineering) and can therefore offer insights as to whether the number of technical and non-technical credit hour requirements tends to be static across engineering programs in the same college, or rather, whether substantial

fluctuations in the total number of technical and non-technical credit hour requirements are also prevalent at the college-level.

For each university, the lowest total number of required technical credit hours (across the four engineering program-types) was subtracted from the highest total number of required credit hours to calculate the largest difference in the required technical credit hours for the studied degree programs. For example, in the case of a university where the undergraduate chemical, civil, electrical, and mechanical engineering degree programs required 101, 100, 97, and 89 technical credit hours, respectively, the largest difference would be 12, calculated by subtracting 89 (the lowest) from 101 (the highest). The largest difference in the total number of required technical credit hours across the four program-types at each university is presented in Figure 4.4. Likewise, the largest difference in the total number of required non-technical credit hours across the four program-types at each university (calculated using the same methodology) is presented in Figure 4.5.

Figure 4.4: The largest difference in the total number of required technical credit hours between four engineering program-types at 15 universities.

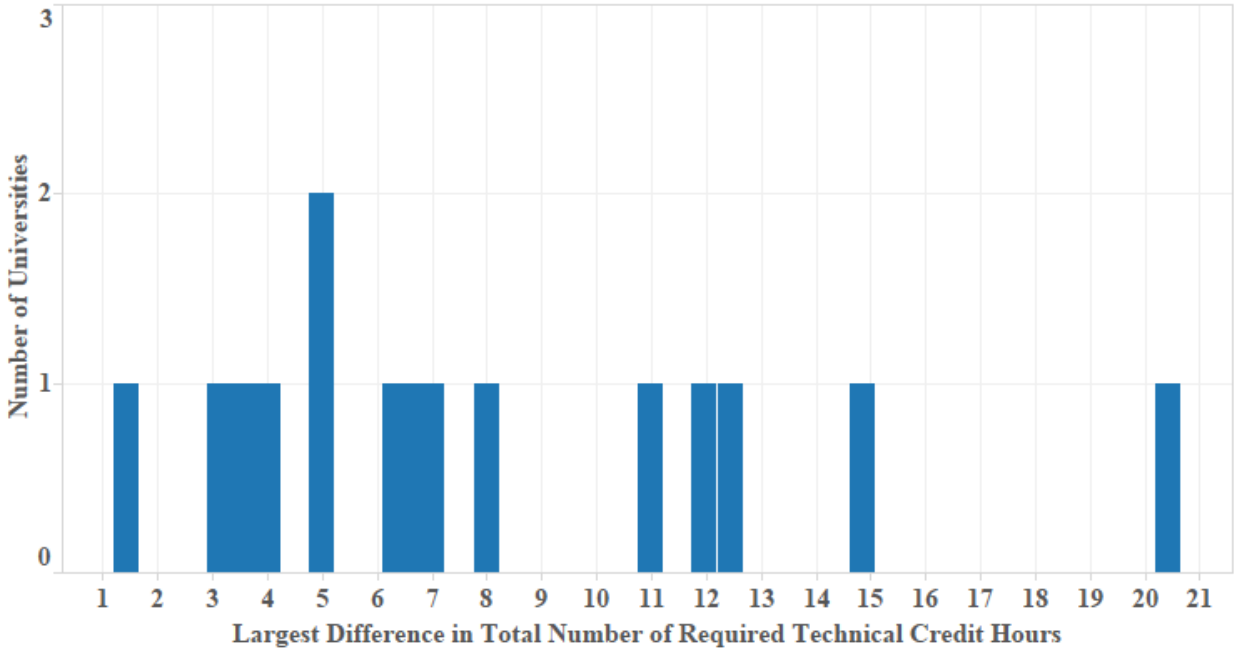
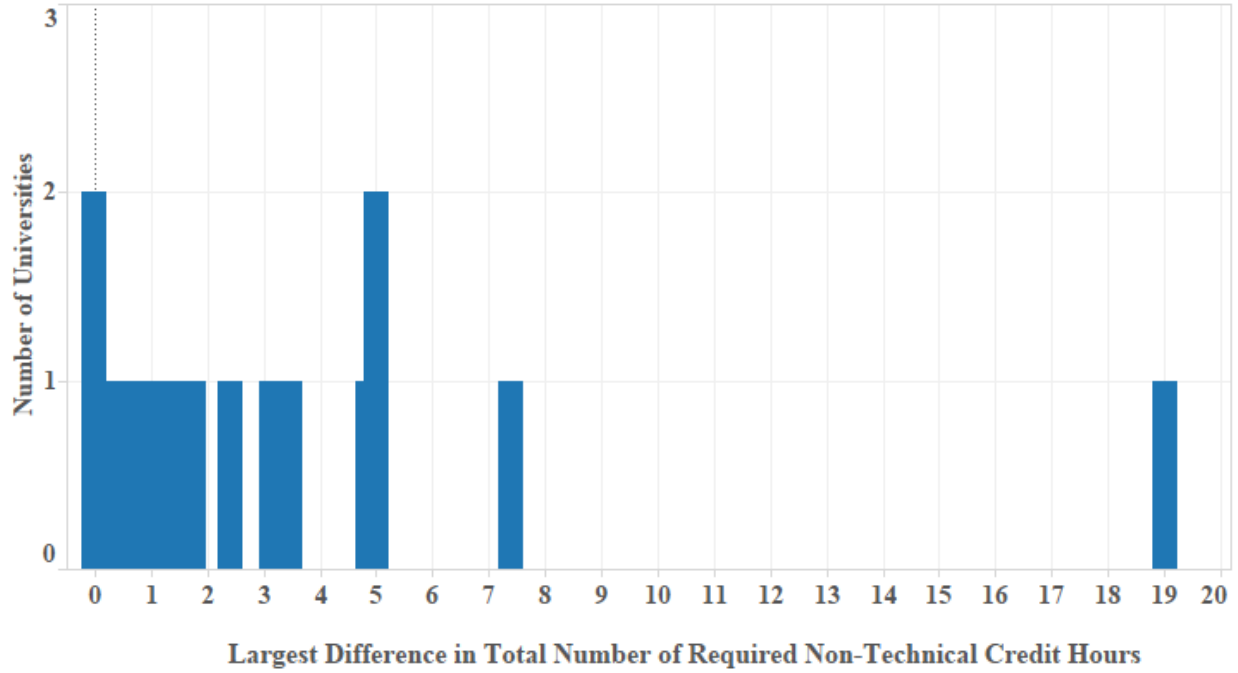


Figure 4.5: The largest difference in the total number of required non-technical credit hours between four engineering program-types at 15 universities.



For this population of 15 universities, the magnitude of differences between technical credit hour requirements for the four engineering disciplines varied from school to school. The smallest difference in technical credit hour requirements was one credit hour, with the largest difference 20 credit hours. This 20 credit hour differential translates to some engineering students taking over *one whole semester* of additional technical courses as compared to their specialized-engineering peers within the same college. It is hard to imagine that such a large difference would not have deleterious social and/or psychological impacts on all engineering students at the college and implicitly contribute to a hierarchical culture where one discipline is perceived as harder than the other "technically-light" disciplines.

While no schools required the same amount of technical credit hours across all four engineering programs, three of the schools required the same amount of non-technical credit hours for students in chemical, civil, electrical, and mechanical engineering, with all but two of the remaining 12 schools having differences in non-technical requirements of five or fewer credit hours.

Generally speaking across these 15 schools it would seem that required technical credit hours commonly vary across engineering disciplines within the same college, but that non-technical credit hours may vary to a lesser extent. These tendencies could suggest that technical requirements are more influenced at a department-level, while non-technical requirements have college-level influences.

The Friedman Analysis of Variance (ANOVA) was used to test for differences in required technical, required non-technical, and possible non-technical credit hours between the four engineering program-types across these 15 universities. Results indicate that no statistically significant differences exist for required technical ($p = 0.135$), required non-technical ($p =$

0.644), or possible non-technical ($p = 0.100$) between the chemical, civil, electrical, and mechanical engineering programs at these universities (see Appendix B for graphs and median values for each analysis). Though statistically insignificant when dealt with as a population, differences (sometimes quite large) *do* exist in the required technical versus non-technical course loads experienced by the engineering students in various disciplines on these college campuses.

These differentials are prone to propagate poor (and likely unconscious) values messages to engineering students and could be indicative of a lack of intentional dialogue about the essential components of engineering education across disciplines within some of these highly-regarded engineering colleges. Based on the dangerous implicit messaging of varied technical requirements between engineering discipline programs within the same college, divergent requirements warrant intentional interdepartmental faculty collaborations to consider adopting a more analogous technical—non-technical balance from program to program and/or more degree program options within each discipline. These recommendations will be further outlined in a later section of this chapter.

Comparing Technical and Non-Technical Credit Hour Requirements to University Data

We have seen that technical and non-technical credit hour requirements for specialized engineering programs commonly vary from university to university as well as from program to program within a given engineering-college. A next logical question is whether a discernable pattern exists as to what types of universities are allocating more or fewer credit hours to technical or non-technical areas of study.

Mann-Whitney U ($\alpha = 0.05$) statistical tests were used to look for significant differences (by engineering program-type) between the Doctoral and No Doctoral universities that house the 103 top-ranked programs in this study for required technical, required non-technical, and

possible non-technical credit hours, respectively. Results indicated that no statistically significant differences exist for required technical, required non-technical, or possible non-technical credit hours between the Doctoral and No Doctoral populations for any of the four engineering disciplines (see Appendix C for graphs, median values, and p-values). In other words, no pattern emerged as to whether Doctoral versus No Doctoral universities tend to allocate more or fewer credit hours to technical or non-technical credit hours.

The Spearman Rank Correlation statistical test was used to test for coefficients of association between ordinal-level institution variables and the required technical, required non-technical, and possible non-technical credit hour data from the 103 degree programs. A table of sample size-based Spearman's rho critical values (Sheskin, 2011) was used to determine statistical significance ($\alpha = 0.01$). See * flagged cells in Table 4.6 for significant values with Spearman's rho coefficients of > +/- 0.4.

Table 4.6: Spearman's rho correlation coefficients.

	2013 FT UG Pop.	2013 FT ENG Pop.	% FT UG Pop. that is ENG	Req'd Tech. Credit Hours	Req'd Non-Tech. Credit Hours	Possible Non-Tech. Credit Hours
2013 FT UG Population	1.000	**.789***	**-.655***	**.411***	-.233	**-.404***
2013 FT ENG Population	**.789***	1.000	-.118	.181	-.040	-.176
% FT UG Pop. that is ENG	**-.665***	-.118	1.000	**-.439***	.381	**.437***
Req'd Tech. Credit Hours	**.411***	.181	**-.439***	1.000	**-.647***	**-.996***
Req'd Non-Tech. Credit Hours	-.233	-.040	.381	**-.647***	1.000	**.658***
Possible Non-Tech Credit Hours	**-.404***	-.176	**.437***	**-.996***	**.658***	1.000

The university full-time undergraduate population was *positively* correlated with full-time undergraduate engineering population, logically indicating that schools with larger student bodies tend to have more engineering students.

Full-time undergraduate population was *negatively* correlated with the percentage of the full-time undergraduate population that is engineering students, meaning that the larger the school is, the *smaller* its engineering population—proportionally speaking—even though there are more engineering students overall.

The total number of required technical credit hours was *positively* correlated with the university full-time undergraduate population, suggesting that *larger universities tend to require their engineering students to take more technical courses*.

Required technical credit hours were *negatively* correlated with the percentage of the full-time undergraduate population that is engineering students, indicating that *more technically-focused schools surprisingly require their engineering students to take fewer technical courses*. One possible reason for this tendency could be that more technically-focused schools are known for being technically-focused and therefore need not flood their degree programs with an overload of technical content to ensure a solid engineering education reputation, or that they are confident enough to value the benefits of non-technical education.

The total number of required non-technical credit hours was *negatively* correlated with required technical credit hours, demonstrating that *degree programs with higher technical requirements tend to have lower non-technical requirements and vice versa*. This relationship is logical given that these are just different ways to allocate a finite number of credits.

Discussion, Conclusions, Future Work

This study examined the distribution of technical versus non-technical coursework for 103 US News & World Report top-ranked and ABET-accredited undergraduate degree programs in chemical, civil, electrical, and mechanical engineering. Findings revealed that a wide range of required technical and non-technical credit hours exists for this population of commonly offered engineering discipline programs, with the required technical and non-technical credit hours varying at most by what translates to almost an entire *year* (out of a four-year program) during which some students would exclusively take technical courses, while others exclusively take non-technical courses, but all graduate with top-ranked ABET-accredited specialized engineering degrees.

Whether this divergence is a reflection of the intentional values and educational philosophy of an institution, or a curriculum that grew organically over time, is worthy of reflection. At any rate, the divergence demonstrates what is *possible* within a highly regarded engineering program with respect to nontechnical content. Engineering students enrolled across these degree programs are certain to have disparate academic experiences and are sure to graduate with divergent skillsets. While graduating engineers with a wide range of skills can be advantageous to meet the complex and evolving needs of society, this result is unsettling if it is a result of inadvertent curriculum choices versus curriculum designed with the end in mind.

Certainly, more—either of technical or non-technical coursework—is not always better, and due to the quantitative nature of this study, we can't have a comprehensive understanding of the true balance and quality of the required techical and non-technical coursework for these degree programs without peering inside the contents of each course. Opportunities to integrate

non-technical content into “technical” courses can—and should—certainly be created (and vice versa), and this study does not capture that level of detail. However these high-level quantitative snapshots of course allocations for dozens of specialized engineeirng programs nationwide are clues as to where respective engineering program’s educational priorities lie—and it would seem that these priorities differ.

It is evident from the range of credit hour requirements (seen for both technical and non-technical coursework and across programs) that widespread consensus does not exist amongst engineering educators regarding the appropriate allocation of technical versus non-technical coursework for a specialized engineering undergraduate education. Also it is clear that there are substantially divergent interpretations amongst engineering educators as to what constitutes adequate “general education” for an engineer. Surely, engineering students enrolled across the studied degree programs have differing academic experiences and graduate with diverse skillsets. An engineering student that devotes all but six courses to engineering, science, and math is likely to graduate into the workforce with a more “technical” skillset and less developed understandings of “non-technical” topics as compared to engineering students at the other end of the curricular balance spectrum who take two courses *every semester* of their four-year degree focused on topics in the humanities, social sciences, or arts.

Though an engineering workforce with mixed skillsets can unquestionably behoove society, it appears that the engineering students themselves don’t necessarily get to choose *which* skillset they will emerge with (differentiated by either additional technical versus nontechnical coursework) and are instead at the mercy of their engineering faculty’s opinions as to the appropriate allocation of technical and non-technical coursework without any governing body refereeing beyond ABET’s minimal general criteria constraints. Enrolled engineering students

disheartened by their program's course allocations but still interested in engineering, then, need to change disciplines (if at a college where curricular balance fluctutes between engineering programs) or switch engineering colleges to find curricular balance more suitable to their needs—which they would only become informed about after a detailed reading of each program's graduation requirements, something most ~18 year old prospective students unfortunately likely don't do when selecting a program. This culture of inconsistent course allocations from program to program within engineering colleges and from university to university could be an obstacle to attracting students *to* and retaining them *in* undergraduate engineering, and it deserves the attention of engineering education researchers.

Intentionally Inviting Diverse Technical and Non-Technical Course Allocations into an Engineering College

So, where to go from here? If we are to make use of the range of possible technical and non-technical course allocations highlighted by this study, we must ensure that this range is *purposeful* and communicated to students. It is recommended that engineering colleges intentionally invite the spectrum of technical and non-technical course allocations into their program selections, offering not only the more traditional, highly technical programs for students with career aspirations well-matched to such an education, but also offer engineering degree program option(s) that likewise make a more balanced technical and non-technical curriculum accessible to students with diverse career interests desiring a customizable, yet technically-focused educational experience.

The options for implementation are plentiful, including expanding to offer flexible "tracks" *within* preexisting engineering discipline programs (such as offering traditional mechanical and flexible mechanical program options housed in the same department), or expanding the engineering college offerings to include distinct engineering programs that

embody customizability and the opportunity for students with broad interests and career aspirations that would be poorly served by the more traditional programs to explore more non-technical courses. The added benefit of a customizable program is that students are provided with (comparatively) more and better opportunities to choose their courses—something commonly lacking in many undergraduate engineering programs (Forbes, Bielefeldt, and Sullivan, 2015; Forbes et al., 2015)—should they desire exploring academically.

Intentionally inviting the *spectrum* of differing proportions of technical and non-technical coursework into engineering programs housed in the same college in this way expands both what is offered to students and how we can serve them and society. An engineering student interested in leading international development projects, for example, might be better served in a program that allows for more non-technical course opportunities, getting a solid engineering underpinning balanced with courses in the language, history, and culture specific to the area in which he or she hopes to work. Conversely, another student interested in a career as a technically-focused aerospace engineer working in industry might find the 18 credit hours of "general eduction" adequate and would be better served by the traditional, more technically-focused, aerospace engineering degree.

It is recommended that colleges currently exclusively offering highly technically focused engineering degree programs (such as those requiring over 100 normalized technical hours) consider expanding their degree program offerings to *also* include selections that mimic the higher non-technical course allocations of other programs detailed in this study. Providing students with both options may serve to broaden engineering participation to students with career interests better served by a more balanced engineering curriculum and begin (or expand) an

intentional conversation about the differences in course allocations for various engineering programs and the students that are best served by them.

As for visualizing the next steps in the evolution of engineering curricula, a look into what today's engineering students do after they graduate signals that the times have changed from the days of myopic technically-focused degree programs matriculating graduates into decades-long careers as technical engineers. Today's engineering college graduates go on to work in countless non-STEM fields such as architecture, arts and entertainment, business, education, health care, non-STEM management, sales, and social services, in addition to careers in math, science, and engineering (United States Census Bureau, 2014). And, our society is well served by technically-literate graduates working in fields that are not traditionally thought of as technical, such as journalism, law, and politics. Still other engineering graduates will go on to work in the engineering profession, and need an engineering education that will ensure they are able to fulfill the trust placed in them by society to perform competently and ethically.

The community of engineering educators should recognize and welcome the evolving—and expanding—role of the engineer in society and become more *intentional* and forward-thinking about differing curricular allocation opportunities. Openly marketing diverse opportunities to prospective students recognizes that students have different needs and aspirations, and that today's complex problems will benefit from solution teams with varied preparations, interests and values that play to their passions. The divergent technical and non-technical credit hour requirements that now seem unsettling (if inadvertent) can thus morph into assets of differentiated engineering educations to better serve society and our students.

CHAPTER 5

EXPLORING IMPROVED FEMALE ENROLLMENT AND GRADUATION OUTCOMES IN FLEXIBLE, AUTONOMY-SUPPORTIVE ENGINEERING PROGRAMS

Abstract

A shortage of female students is prevalent in most engineering disciplines. Previous studies have demonstrated that engineering programs commonly offer students comparatively few academic exploration opportunities to choose their own courses. Preliminary survey and enrollment findings led to the hypothesis that engineering programs offering greater curricular flexibility and opportunities to choose courses may differentially appeal to female students. This quantitative study explored whether discernable patterns exist that are suggestive of increased *course choice opportunity* (free electives, technical electives, etc.) holding differentially high appeal or importance to female undergraduate engineering students. Results across 43 top-ranked engineering schools demonstrated a positive correlation between the college's percent of engineering bachelor's degrees earned by women and the median free elective credit hours the college offers to engineering students. Significant correlations were found between course choice opportunity and percentage female enrollments in chemical, civil, electrical, and mechanical engineering programs. The results point to the need for additional research to ascertain whether and *how* engineering programs can work to attract and graduate more female students—and all students—by cultivating more autonomy-supportive undergraduate educational experiences.

Background

Though women make up over half of the college population (National Center for Education Statistics, 2014), they make up less than 20 percent of the undergraduate engineering bachelor's degree recipients (ASEE, 2013), compared to about 40 percent in mathematics and the physical sciences and 60 percent in the biological sciences (National Center for Education Statistics, 2013). Numerous studies indicate that in most engineering disciplines there is no differential attrition by gender (Costentino de Cohen and Deterding, 2009; Hartman and Hartman, 2006; Lord et al., 2008; Ohland et al., 2008; Seymour and Hewitt, 1997), and that the large gender disparities among graduates are due to the low initial enrollment of women in engineering, rather than poor differential retention (Costentino de Cohen and Deterding, 2009). And, while high school students are increasingly drawn to STEM careers and college majors, female interest is decreasing (myCollegeOptions & STEMconnecter, 2012; Robelen, E., 2013)—with the gender gap the widest for engineering.

This disparity of female enrollment between engineering and the aforementioned non-engineering STEM disciplines begs the yet unanswered question of why so many women find other undergraduate science and math programs more appealing. Previous studies have established that there is a widespread deficiency of *course choice opportunities*—opportunities over the course of a degree program for students to choose their courses, such as free electives, humanities electives, or technical electives—in engineering (Forbes, Bielefeldt, and Sullivan, 2015; Forbes, et al. 2015, 2015), with engineering programs providing substantially less course choice opportunity to students as compared to the non-engineering STEM disciplines (Forbes et al., 2015) that are relishing markedly better female enrollments. In a study spanning 38 universities, engineering students were afforded a median of 3% of their curriculum as free

electives, as compared to physics, chemistry, and math students at the same universities whose degree programs were comprised of 15%, 17%, and 22% free electives, respectively (Forbes et al., 2015). This course choice opportunity disparity that is so prevalent between engineering and non-engineering STEM degree programs on campuses nationwide has yet to be explored as a possible contributor to the comparative lack of women choosing engineering pathways; the present study serves as a starting point for this work.

Anecdotal findings suggest that, though all students need experiences to make choices (Deci et al., 1991; Ryan and Deci, 2000), engineering programs with comparatively increased course choice opportunity and flexibility may be differentially appealing to women. In November, 2012, 24% of the University of Colorado, Boulder undergraduate engineering students (n=821) responded to a short-answer, 7 point Likert-scale survey, wherein 48% of survey respondents (n=391) "agreed" or "strongly agreed" that they would "like the flexibility to customize [their] engineering degree program through an individualized, negotiated curriculum," including 46% of male (n=261) student respondents, and a higher percentage, 53%, of female (n=121) student respondents (note: nine of the 391 student respondents chose not to identify as male or female). Results of a Pearson Chi Squared test on these findings revealed a $p = 0.071$. When looking specifically at students who "strongly agreed" to wanting a flexible, customizable engineering program, the Pearson Chi Squared test between male and female respondents revealed a $p = 0.001$, with female students finding such a program more desirous than male students.

The Massachusetts Institute of Technology (MIT) offers students a traditional mechanical engineering degree program (Course 2) as well as a *flexible* mechanical engineering degree program (Course 2-A) that is "designed for students whose academic and career goals demand

greater breadth and flexibility than are allowed under the mechanical engineering program" and "allows students an opportunity to tailor a curriculum to their own needs, starting from a solid mechanical engineering base" (MIT, 2015). A comparison of average female enrollment percentages for MIT's traditional versus flexible mechanical engineering degree programs for first through fourth/fifth-year students from 2006-2011 revealed that the flexible program had higher average percent female enrollment ($\mu = 40.53$) than the traditional program ($\mu = 35.02$), bringing it close to the average percentage female enrollment for the college overall ($\mu = 40.16$) (ASEE, 2006-2011). A pair-wise Mann-Whitney U test confirmed a statistically significant difference between traditional mechanical and flexible mechanical percent female enrollments for those years at the $\alpha = 0.05$ level ($p = 0.010$). This differentially higher level of female enrollment in the flexible program is of particular interest given that mechanical engineering degree programs nationwide awarded the third lowest percentage of bachelor's degrees to women in 2013, as compared to 21 other engineering disciplines (ASEE, 2013).

Previous research has suggested that differences *do* exist in the academic motivations of male versus female university students, with female students "display[ing] a more self-determined motivational profile than male students" (Vallerand et al., 1992). This chapter serves as a preliminary quantitative exploration into whether discernable large-scale patterns exist that are suggestive of increased course choice opportunity holding differentially high appeal to female engineering students.

Research Questions

- Do engineering colleges that offer students comparatively more course choice opportunity award a differentially higher percentage of bachelor's degrees to women as compared to those that offer less course choice opportunity?
- Do specialized engineering degree programs affording students comparatively more course choice opportunity have differentially high percentage female enrollments as compared to specialized engineering degree programs that provide their students with less course choice opportunity?

Methods

Engineering College Course Choice Opportunities and the Percentage of Bachelor's Degrees Awarded to Women

In order to investigate whether the course choice opportunities offered by engineering colleges correlate to the percentage of engineering bachelor's degrees they award to women, a quantitative analysis was conducted using data from the 2013 US News & World Report's top-ranked 22 engineering schools where doctoral programs are offered and the top-ranked 24 engineering schools where doctoral programs are not offered. These datasets are a continuation of a previous study, *Course Choice Opportunity in Undergraduate Engineering Education: National Trends and Autonomy-Supportive Exceptions*, from Forbes et al. in 2015.

Course choice opportunity data for each engineering college was gathered using the 2013-2014 online university catalog. Four previously established (Forbes, Bielefeldt, and Sullivan, 2015; Forbes et al., 2015, 2015) choice variable metrics, *Total Free Elective Credit Hours* ("free electives"), *Total Choice Count* ("total choice"), *Weighted Choice Score* ("weighted choice"), and *Average Choice per Opportunity*, were used to quantify the course

choice opportunities afforded to engineering students enrolled in each of the Engineering Accreditation Commission (EAC) Accreditation Board for Engineering and Technology (ABET) accredited engineering degree programs offered by each of the studied engineering schools. These choice variable metrics are further defined in the next section of this chapter. In each case, choice variable data was normalized to 130 total degree credit hours as a continuation of the previous studies that probed this dataset and employed these choice variable metrics (Forbes, Bielefeldt, and Sullivan, 2015; Forbes et al., 2015, 2015).

For each engineering school, a median value for each of the four course choice variables was calculated from the course choice opportunity data across all EAC ABET-accredited programs offered by the engineering school. These median values paint a portrait of the typical course choice opportunity for each engineering school and in each case were compared to the engineering school's percentage of bachelor's degrees awarded to women for the 2013-2014 academic year (ASEE, 2014).

The lowest *total number* of engineering bachelor's degrees awarded to both men and women for the 2013-2014 academic year across the 22 engineering schools where doctoral programs are offered was over 150. The larger size of the engineering schools and, by extension, the more bachelor's degrees they award each year, makes them less prone to significant annual fluctuations. Three of the 24 engineering schools where doctoral programs are *not* offered were eliminated from this study because they awarded fewer than 50 total engineering bachelor's degrees for the 2013-2014 academic year, thereby leaving a total of 21 non-doctoral awarding institutions in this study.

The choice variable and bachelor's degree data used were based on counts and are therefore ordinal in nature. As such, the nonparametric Spearman Rank Correlation statistical test was used to test for coefficients of association between percentages of engineering school bachelor's degrees awarded to women and the engineering school median choice variable values. Sheskin's table of critical values for Spearman's rho (Sheskin, 2003) was used to determine statistical significance based on sample size. Because this is an exploratory study, lacking flexibility with regard to increasing sample size, liberal two-tailed significance levels of $\alpha = 0.10$ were used to increase power and capture all levels of significance that may merit further inquiry.

Course Choice Opportunity and Percentage Female Enrollments in Specialized Engineering Degree Programs

In order to investigate whether the course choice opportunities offered by specialized engineering degree programs impact their percentage female enrollments, a second quantitative analysis was conducted using data from the 2015 US News & World Report's 83 top-ranked undergraduate schools for chemical, civil, electrical, and mechanical engineering. This program dataset is a continuation of a previous study, *Course Choice Opportunity in Specialized Engineering Degree Programs: Re-thinking Undergraduate Engineering to Better Support Student Psychological Need*, from Forbes et al. in 2015. The chosen engineering disciplines are representative of a range of the percentage of engineering bachelor's degrees awarded to women by discipline in 2013: chemical engineering (32%), civil engineering (21%), mechanical engineering (13%), and electrical engineering (12%) (ASEE, 2013).

The selected US News & World Report rankings were specific to engineering schools where doctorate programs are offered, so as to intentionally filter for larger degree programs that would be less prone to annual fluctuations in percentage female enrollments. In addition, five

degree programs that awarded fewer than 20 total bachelor's degrees last year were eliminated from this population of 83, leaving a total of 78 programs: 21 chemical, 16 civil, 19 electrical, and 22 mechanical engineering degree programs. Due to the smaller civil engineering sample size of 16 programs, four civil engineering programs from the 2013 US News & World Report's top-ranked 22 engineering *schools* where doctoral programs are offered *and* awarded greater than 20 bachelor's degrees that year were also added to the dataset, bringing the total civil engineering sample size for the exploratory study to 20 degree programs (and the overall total for the study to 81 degree programs). Each of the 81 degree programs is EAC ABET-accredited and housed in a university classified by Carnegie (Carnegie Classification of Institutions of Higher Learning, 2015) as "Research Universities (very high research activity)" (RU/VH).

Again, course choice opportunity data for each engineering college was gathered using the 2013-2014 online university catalog in terms of the four choice variable metrics, Total Free Elective Credit Hours, Total Choice Count, Weighted Choice Score, and Average Choice per Opportunity. Choice variable data for this analysis was also normalized to 130 total degree credit hours. The course choice opportunity possibilities for each of four engineering disciplines are not favored or hindered by ABET's accreditation criteria, which is outcomes-based and highly conducive to course choice opportunity (Forbes et al., 2015, 2015).

Here, the Spearman Rank Correlation statistical test was used to test for coefficients of association between choice variable values for each of the engineering program types (chemical, civil, electrical, and mechanical engineering) and 1) program percent female enrollments, 2) program percentage of bachelor's degrees awarded to women, and 3) engineering college percent female enrollment (ASEE, 2013). As before, Sheskin's table of critical values for Spearman's

rho (Sheskin, 2003) was used to determine statistical significance based on sample size for a liberal two-tailed significance level of $\alpha = 0.10$.

The Four Course Choice Variables

Total Free Elective Credit Hours ("free electives") is the total number of credit hours (normalized to a 130 credit hour degree program) for which students may choose, with no restrictions, any courses of their liking and have them apply to their total credit hour requirement for graduation.

Total Choice Count ("total choice") is the total number of normalized credit hours for which students are afforded course options, including *all* course choice opportunities, such as free electives, humanities electives, technical electives, or the opportunity to choose courses from a lists of options.

Weighted Choice Score ("weighted choice") is designed to add a dimension of choice *magnitude* to the Total Choice Count, and is calculated using a weighted matrix design. Each course choice opportunity is categorized as one of four choice-types (Table 5.1), and entered into the corresponding cell (**I**, **J**, **K**, or **L**) of the weighted matrix presented in Table 5.2.

Table 5.1. The four Weighted Choice Score course choice opportunity categories.

Category	Definition	Examples	Weight
1	Opportunities for which courses are chosen from a list of options.	"Choose 1 of the following 3 courses" "Choose one course from the following list of options"	3
2	Instances when courses are chosen from one department *or* engineering electives.	"Chemistry elective," "Philosophy elective," "Civil Engineering elective"	22
3	Opportunities to choose courses outside of engineering, from more than one department.	"humanities elective," "social sciences elective", "technical elective"	88
4	Free elective course choice opportunities.	There are no restrictions on course choice opportunities; students may choose any course.	1292

The weights for the four matrix categories (3, 22, 88, and 1292, respectively) originate from a previous study (Forbes, Bielefeldt, and Sullivan, 2015), and are based on the median raw counts of the actual numbers of courses students get to pick from when afforded with each course choice opportunity-type. As such, these weights are designed to capture the *magnitude* of choice for each type of course choice opportunity. Table 5.2, below, shows the full weighted matrix design and calculations of Total Choice Count and Weighted Choice Score choice variable values for a sample degree program.

Table 5.2. The course choice opportunity weighted matrix design and example.

Engineering Degree Program	Cat. 1	Cat. 2	Cat. 3	Cat. 4	**Total Choice Count**	**Weighted Choice Score**
	3 **A**	22 **B**	88 **C**	1292 **D**		
	Weighted Fractions / 1292					
	.0023 **E**	.0170 **F**	.0681 **G**	1 **H**		
Mechanical Engineering	9 **I**	6 **J**	12 **K**	2 **L**	29 **M**	2.9 **N**

- Cells **A→D** show the original matrix weights.
- Cells **E→H** contain the actual weights used in calculations, fractions calculated by individually dividing **A→D** by **D**.
- Cells **I→L** contain frequency counts (in credit hours) of the four respective course choice categories. In this example, the Mechanical Engineering degree has 9 credit hours of Category 1 choices (**I**), 6 credit hours of Category 2 choices (**J**), 12 credit hours of Category 3 choices (**K**), and 2 credit hours of Category 4 choices (**L**).
- *Total Choice Count*: **M** = **I** + **J** + **K** + **L**.
- *Weighted Choice Score*: **N** = (**I*****E**) + (**J*****F**) + (**K*****G**) + (**L*****H**).

Average Choice per Opportunity

Average Choice per Opportunity is the average magnitude of choice for every course choice opportunity students are afforded, and is calculated by dividing Weighted Choice Score over Total Choice Count. For the Table 5.2 example, Average Choice per Opportunity = **N** / **M** = 2.9 / 29 = 0.10.

Microsoft Excel 2013 was used for data collection in this study. The Statistical Package for the Social Sciences (SPSS) 23 was used to conduct the Spearman Rank Correlation tests.

Results

Engineering College Course Choice Opportunities and the Percentage of Bachelor's Degrees Awarded to Women

The median free elective credit hours offered to engineering students in the 43 top-ranked engineering schools—22 Doctoral institutions and 21 No Doctoral institutions—and their corresponding 2013-2014 percentage of engineering bachelor's degrees that were awarded to women are presented in Figures 5.1 and 5.2, respectively.

Figure 5.1: Median free elective credit hours by engineering college versus the 2013-2014 percent of college engineering bachelor's degrees awarded to women for 22 Doctoral Schools.

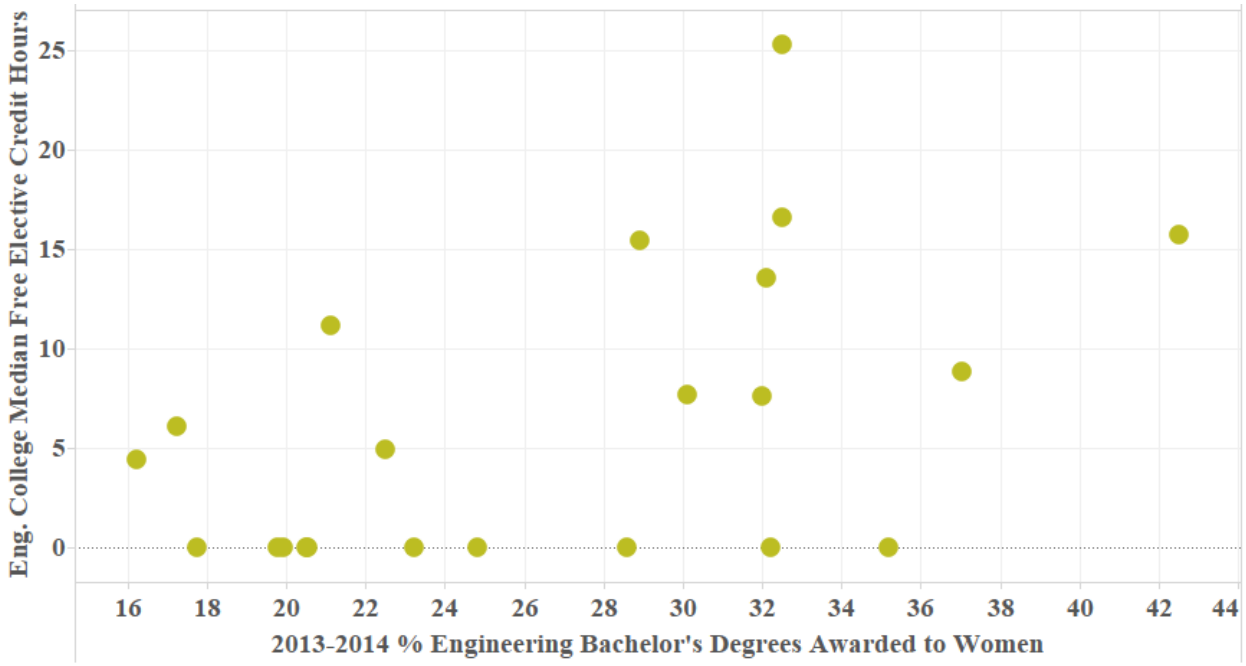
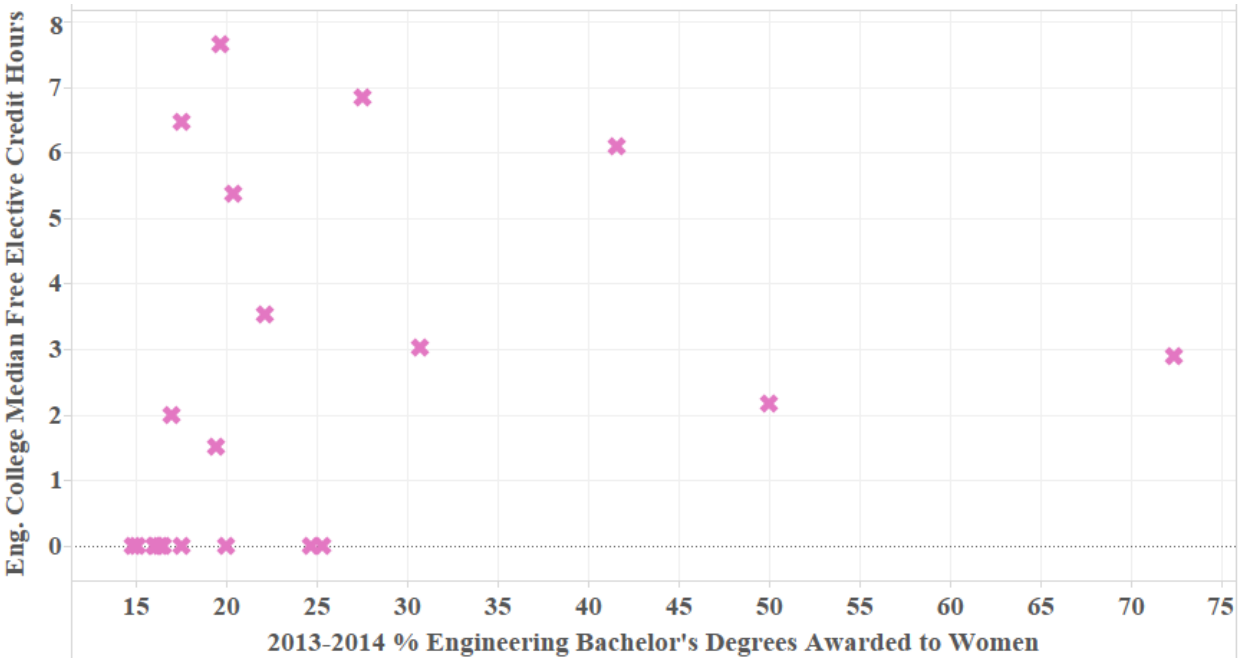


Figure 5.2: Median free elective credit hours by engineering college versus the 2013-2014 percent of college engineering bachelor's degrees awarded to women for 21 No Doctoral Schools.



The Doctoral schools and No Doctoral schools had similar Spearman's rho correlation coefficients of 0.500 and 0.546, respectively, each of which is significant at the $\alpha = 0.05$. In each case, these findings are indicative of a *positive* correlation between the free elective credit hours offered to engineering students in a college and the college's percent of engineering bachelor's degrees that are awarded to women.

The median Total Choice Counts for EAC ABET-accredited programs for the 43 top-ranked engineering schools, again separated into Doctoral and No Doctoral categories, and their corresponding 2013-2014 percentage of engineering bachelor's degrees that were awarded to women are presented in Figures 5.3 and 5.4.

Figure 5.3: Median Total Choice Count values by engineering college versus the 2013-2014 percent of college engineering bachelor's degrees awarded to women for 22 Doctoral Schools.

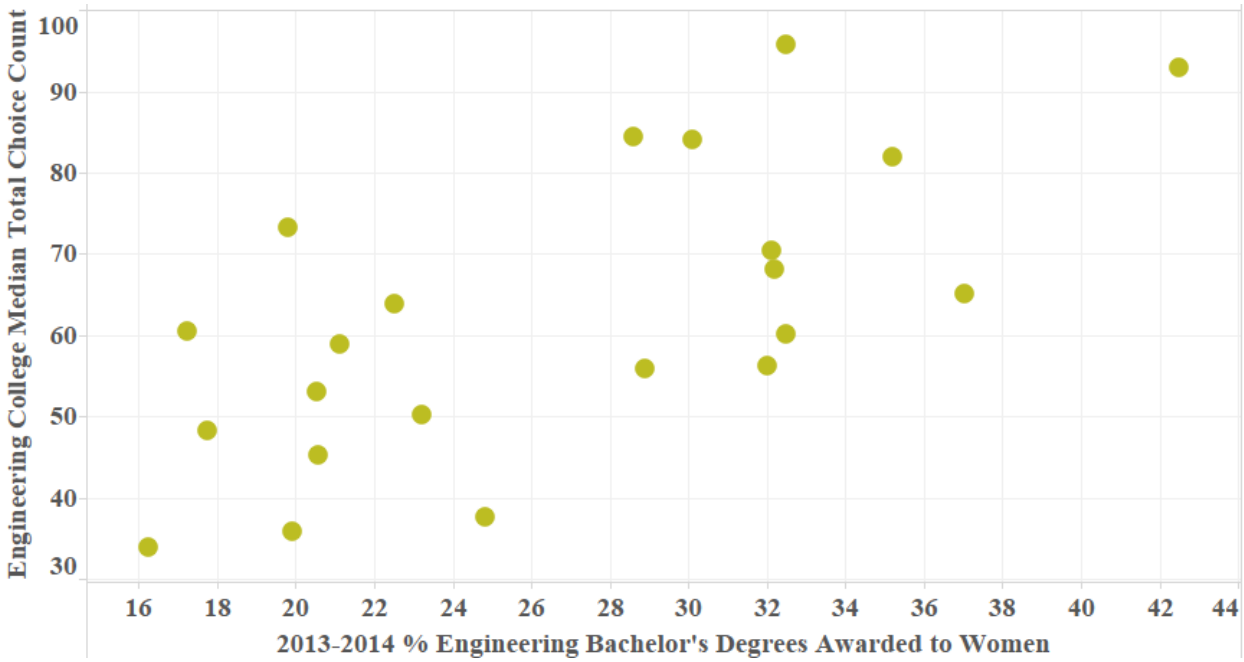
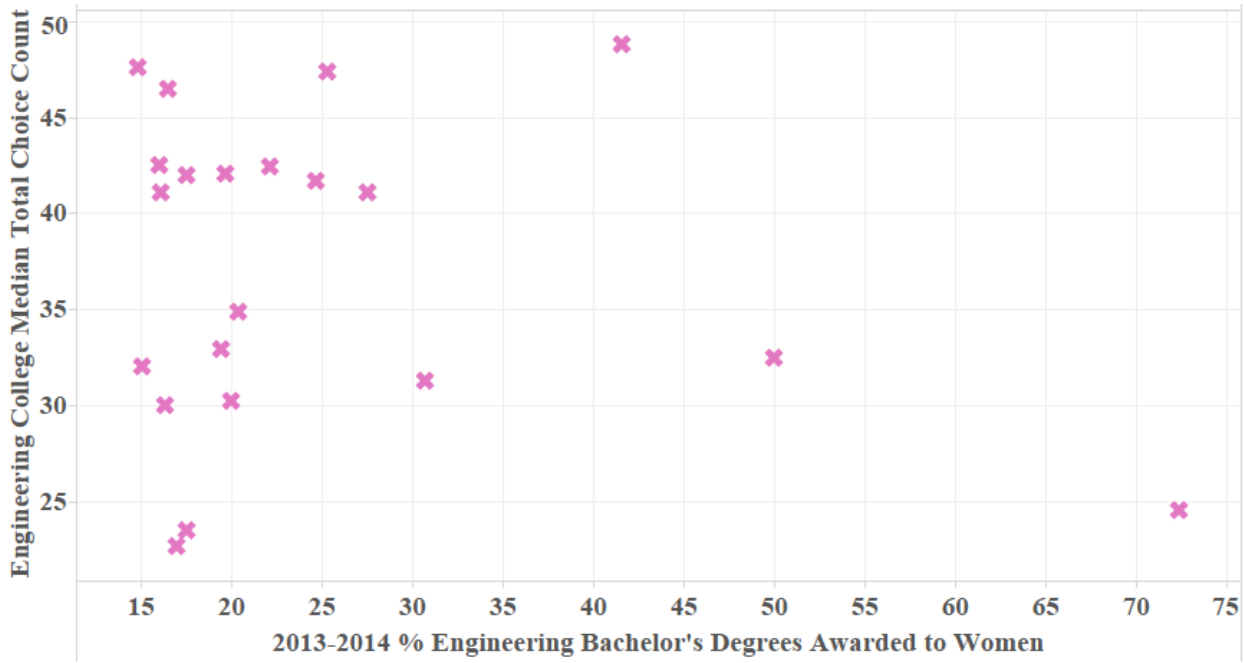


Figure 5.4: Median Total Choice Count values by engineering college versus the 2013-2014 percent of college engineering bachelor's degrees awarded to women for 21 No Doctoral Schools.



Here, the Doctoral schools had a correlation coefficient of 0.622 (significant at $\alpha = 0.01$), while the No Doctoral schools had quite a different *non*-significant value of -0.20. These results indicate that there is a *positive* correlation between the total number of opportunities engineering students in a Doctoral college get to choose their courses and the college's percent of engineering bachelor's degrees that are awarded to women—but these findings do not extend to No Doctoral institutions. Contributing to this disagreement is the influence of several outlying schools in the No Doctoral dataset that award unusually high percentages of their engineering bachelor's degrees to women. These schools are comparatively small, and in each case engineering makes up a significant portion of their undergraduate student body. It is hypothesized that institution variables beyond the scope of this exploratory quantitative study, such scholarships and higher percentages of engineering female faculty members, likely also contribute to the comparatively very high percentages of bachelor's degrees awarded to women at these schools.

For Weighted Choice Score, statistically significant correlations (for a two-tailed $\alpha = 0.05$ level) were found for Doctoral and No Doctoral institutions, respectively, and the percent of college engineering bachelor's degrees awarded to women (Spearman's rho correlation coefficients were 0.390, and 0.418, respectively). See Appendix D for the graph. As with the free electives results presented earlier, in each case, these findings are indicative of a *positive* correlation between the Weighted Choice Score—or *magnitude* of choice—provided to engineering students in a college and the college's percent of engineering bachelor's degrees that are awarded to women.

For the Average Choice per Opportunity choice metric, the Spearman's rho correlation coefficient for Doctoral institutions was 0.176, which is *not* statistically significant, whereas the

Spearman's rho correlation coefficient for No Doctoral institutions was 0.444, which *is* statistically significant at the $\alpha = 0.05$ level. See Appendix D for the graph.

Course Choice Opportunity and Percentage Female Enrollments in Specialized Engineering Degree Programs

Spearman's rho correlation coefficients for tests run between the 78 top-ranked specialized degree program choice variable values, percent female enrollments in the specialized engineering *programs*, percent female enrollments in the engineering *colleges*, and percent of specialized engineering program degrees awarded to women are presented in Tables 5.3 – 5.6. In all cases, two-tailed levels of significance based on sample size are flagged with bold font and shaded cells for an exploratory $\alpha = 0.10$ level.

Table 5.3: Spearman's rho correlation coefficients for 21 *chemical engineering* programs.

	% Female Enroll. ENG College $\tilde{x}$ =24	% Chem. ENG Bach Degrees Awarded to Women $\tilde{x}$ =32	% Female Enroll. in Chem. ENG $\tilde{x}$ =33	Chem Program Free Elective Credit Hours $\tilde{x}$ =0	Chem Program Total Choice Count $\tilde{x}$ =45	Chem Program Weighted Choice Score $\tilde{x}$ =2	Chem Program Ave. Choice per Opp. $\tilde{x}$ =0.04
% Female Enrollment in ENG College	1.000	**.644***	**.601***	.300	**.666***	**.531**	.066
% Chemical ENG Bachelor's Degrees Awarded to Women	**.664***	1.000	**.776***	.106	.283	.254	-.077
% Female Enrollment in Chemical ENG	**.601***	**.776***	1.000	.159	.209	.172	-.051
Chem Program Total Free Elective Credit Hours	.300	.106	.159	1.000	.187	**.841***	**.839***
Chem Program Total Choice Count	**.666***	.283	.209	.187	1.000	**.457**	-.109
Chem Program Weighted Choice Score	**.531**	.254	.172	**.841***	**.457**	1.000	**.765***
Chem Program Ave. Choice per Opp.	.066	-.077	-.051	**.839***	-.109	**.765***	1.000

Note: Spearman's rho values > .370 have a two-tailed level of significance at an α = 0.10 level for a sample size of 21 (Sheskin, 2003).
**Indicates significance at an α = 0.01 level*

For the 21 studied chemical engineering programs, the percentage of Bachelor's degrees awarded to women in 2013 ranged from 23 to 61; the median was 32%, which is equal to the

national average for chemical programs in the same year (ASEE, 2013). The percentage of female enrollment for these 21 programs ranged from 26 to 50, with a median of 33. For these chemical programs, then, percentage female enrollments was comparable to the percentage of females earning degrees.

Findings show significant (and logical) positive correlations between the percent female enrollment in engineering colleges, and the percent female enrollment in those college's chemical engineering programs, as well as the percentage of chemical engineering bachelor's degrees awarded to women. The same correlations were found for civil, electrical, and mechanical engineering degree programs (see Tables 5.4 – 5.6 below).

Results for each of the engineering program-types also show significant correlations amongst the choice variable values, which is unsurprising considering that their calculations influence one another.

Also of note is the significant positive correlation between chemical engineering program total choice and the percentage female enrollment in the engineering college, as well as the positive correlation between chemical engineering weighted choice and the percentage female enrollment in the engineering college. These same correlations were found for electrical and mechanical engineering programs, and may suggest that higher female enrollments tend to prevail in engineering college environments that are more autonomy-supportive of students in terms of providing them more opportunities to choose their courses in specialized engineering programs. These findings could also suggest that these choice variable metrics are proxies for by-products of complex engineering college *ecosystems* that as a whole are more appealing to and/or more supportive of female students in particular. If so, a multifaceted ecosystem would probably not be readily replicated by other engineering schools looking to improve female

enrollments simply by increasing course choice opportunities in their degree programs and otherwise remaining stagnant (perhaps with no female faculty members, or countless other attributes that can have the combined effect of deterring female students).

Table 5.4: Spearman's rho correlation coefficients for 20 *Civil Engineering* programs.

	% Female Enroll. ENG College $\tilde{x}$ =25	% Civil ENG Bach Degrees Awarded to Women $\tilde{x}$ =28	% Female Enroll. in Civil ENG $\tilde{x}$ =37	Civil Program Free Elective Credit Hours $\tilde{x}$ =0	Civil Program Total Choice Count $\tilde{x}$ =66	Civil Program Weighted Choice Score $\tilde{x}$ =2	Civil Program Ave. Choice per Opp. $\tilde{x}$ =0.04
% Female Enrollment in ENG College	1.000	**.569**	**.809***	.099	**.413**	.038	-.013
% Civil ENG Bachelor's Degrees Awarded to Women	**.569**	1.000	**.567**	.208	.194	.082	.022
% Female Enrollment in Civil ENG	**.809***	**.567**	1.000	.248	**.535**	.198	.125
Civil Program Total Free Elective Credit Hours	.099	.208	.248	1.000	.187	**.849***	**.852***
Civil Program Total Choice Count	**.413**	.194	**.535**	.187	1.000	.245	.165
Civil Program Weighted Choice Score	.038	.082	.198	**.849***	.245	1.000	**.990***
Civil Program Ave. Choice per Opp.	-.013	.022	.125	**.852***	.165	**.990***	1.000

Note: Spearman's rho values > .380 have a two-tailed level of significance at an α = 0.10 level for a sample size of 22 (Sheskin, 2003).
**Indicates significance at an α = 0.01 level*

For the 20 studied civil engineering programs, the percentage of Bachelor's degrees awarded to women in 2013 ranged from 16 to 89; the median was 28%, which is higher than the national average for civil programs of 21% from the same year (ASEE, 2013). The percentage of female enrollment for these 20 programs ranged from 14 to 56, with a median of 37.

For the civil engineering programs studied (like the chemical, electrical, and mechanical results) there was a significant positive correlation between civil engineering program Total Choice Counts and the percentage female enrollment in the engineering college. A significant positive correlation was also found between civil engineering total choice and the percentage female enrollment in the civil degree program. However, *unlike* the chemical, electrical, and mechanical engineering results—no statistically significant correlations were found between the degree program weighted choice values and the percentage female enrollment in the engineering college.

Table 5.5: Spearman's rho correlation coefficients for 19 *Electrical Engineering* programs.

	% Female Enroll. ENG College $\tilde{x}$ =24	% Elect. ENG Bach Degrees Awarded to Women $\tilde{x}$ =14	% Female Enroll. in Elect. ENG $\tilde{x}$ =15	Elect. Program Free Elective Credit Hours $\tilde{x}$ =2	Elect. Program Total Choice Count $\tilde{x}$ =68	Elect. Program Weighted Choice Score $\tilde{x}$ =3	Elect. Program Ave. Choice per Opp. $\tilde{x}$ =0.05
% Female Enrollment in ENG College	1.000	**.747***	**.839***	.320	**.561**	**.404**	.167
% Elect. ENG Bachelor's Degrees Awarded to Women	**.747***	1.000	**.774***	.332	.344	**.459**	.312
% Female Enrollment in Elect. ENG	**.839***	**.774***	1.000	**.396**	.274	**.428**	.327
Elect. Program Total Free Elective Credit Hours	.320	.332	**.396**	1.000	.273	**.946***	**.933***
Elect. Program Total Choice Count	**.561**	.344	.274	.273	1.000	**.429**	.065
Elect. Program Weighted Choice Score	**.404**	**.459**	**.428**	**.946***	**.429**	1.000	**.913***
Elect. Program Ave. Choice per Opp.	.167	.312	.327	**.933***	.065	**.913***	1.000

Note: Spearman's rho values > .391 have a two-tailed level of significance at an α = 0.10 level for a sample size of 19 (Sheskin, 2003).
**Indicates significance at an α = 0.01 level*

For the 19 studied electrical engineering programs, the percentage of Bachelor's degrees awarded to women in 2013 ranged from 6 to 29; the median was 14%, which is slightly higher than the national average for electrical programs of 12% from the same year (ASEE, 2013). The

percentage of female enrollment for these 19 programs ranged from 10 to 32, with a median of 15. Like the 21 studied chemical programs, the percentage female enrollments for these electrical programs was comparable to the percentage of females earning degrees.

A significant positive correlation was found between the Weighted Choice Score values for the top-ranked electrical engineering programs and their percentage female program enrollments as well as their percentage of bachelor's degrees awarded to women. These same correlations were found for the mechanical engineering degree programs included in this study.

Table 5.6: Spearman's rho correlation coefficients for 22 *Mechanical Engineering* programs.

	% Female Enroll. ENG College $\tilde{x}$ =24	% Mech. ENG Bach Degrees Awarded to Women $\tilde{x}$ =15	% Female Enroll. in Mech. ENG $\tilde{x}$ =16	Mech. Program Free Elective Credit Hours $\tilde{x}$ =4	Mech. Program Total Choice Count $\tilde{x}$ =48	Mech. Program Weighted Choice Score $\tilde{x}$ =6	Mech. Program Ave. Choice per Opp. $\tilde{x}$ =0.12
% Female Enrollment in ENG College	1.000	**.625***	**.666***	.262	**.591***	**.488**	.236
% Mech. ENG Bachelor's Degrees Awarded to Women	**.625***	1.000	**.614***	**.445**	**.632***	**.620***	**.428**
% Female Enrollment in Mech. ENG	**.666***	**.614***	1.000	**.498**	.349	**.445**	**.390**
Mech. Program Total Free Elective Credit Hours	.262	**.445**	**.498**	1.000	.239	**.889***	**.939***
Mech. Program Total Choice Count	**.591***	**.632***	.349	.239	1.000	**.556***	.220
Mech. Program Weighted Choice Score	**.488**	**.620***	**.445**	**.889***	**.556***	1.000	**.906***
Mech. Program Ave. Choice per Opp.	.236	**.428**	**.390**	**.939***	.220	**.906***	1.000

Note: Spearman's rho values > .361 have a two-tailed level of significance at an α = 0.10 level for a sample size of 22 (Sheskin, 2003).
**Indicates significance at an α = 0.01 level*

For the 22 studied mechanical engineering programs, the percentage of Bachelor's degrees awarded to women in 2013 ranged from 9 to 43; the median was 15%, which is slightly

higher than the national average for mechanical programs of 13% from the same year (ASEE, 2013). The percentage of female enrollment for these 22 programs ranged from 2 to 44, with a median of 16. As with the studied chemical and electrical programs, therefore, the percentage female enrollments for these mechanical programs was comparable to the percentage of females earning degrees.

The mechanical engineering programs had the largest number of significant, positive correlations between the degree program choice variable values and the female enrollment and graduation metrics. In addition to the correlations already discussed, significant correlations were found for percentage female enrollment in mechanical engineering and the percentage of the mechanical program bachelor's degrees awarded to women across each of the four choice variable metrics, with the sole exception of Total Choice Count and percent female enrollment which had a Spearman's rho value just below the critical value for significance.

Comparing Correlations Across Engineering Disciplines

Table 5.7 presents a summary of the Spearman's Rho correlation coefficients from Tables 5.3 through 5.6 of the chemical, civil, electrical, and mechanical programs' total choice and free elective scores versus the percentage of program bachelor's degrees awarded to women.

Table 5.7: Spearman's rho correlation coefficients for chemical, civil, electrical, and mechanical engineering program data compared to the nationwide average percentages of bachelor's degrees awarded to women, by discipline.

Engineering Discipline	Nationwide Average % Bach Degrees Awarded to Women	Spearman's Rho corr. coeff. between % Bach degrees to women by program v. program Total Free Elective Credit Hours	Spearman's Rho corr. coeff. between % Bach degrees to women by program v. program Total Choice Count
Chemical (n = 21)	32	0.106	0.283
Civil (n = 20)	21	0.208	0.194
Electrical (n = 19)	13	0.332	0.334
Mechanical (n = 22)	12	**0.445***	**0.632***

**Indicates a two-tailed level of significance at an α = 0.05 level (Sheskin, 2003).*

Looking at these program correlations next to the nationwide average percentages of the bachelor's degrees awarded to women by discipline, it is interesting to note that the correlations are not significant for chemical engineering, which—of the four disciplines—is nationally the "most popular" with women in terms of the national percentages of degrees awarded. The correlations were also not significant for civil and electrical engineering, though the correlation coefficients were increasing in value. Finally, for mechanical engineering—the discipline that is nationally the *least* popular with women (again in terms of the percentages of bachelor's degrees awarded)—these correlations *were* significant. These lead to the question as to whether course choice opportunities hold more importance, value, or appeal to women in the disciplines nationally *less* popular with women. That is to say, it is possible that in programs *less* popular with women (such as mechanical engineering), offering increased course choice opportunity in a given program is comparatively more correlated to the female interest in that program? And if so, might increasing the flexibility and/or customizability in engineering discipline programs via

course choice opportunities be an opportunity to attract more female students to engineering? More work is needed to explore these curious results and ascertain whether increased course choice opportunity may be an avenue to gender diversity in undergraduate engineering education.

Discussion, Conclusions, Future Work

This exploratory study probed large quantitative datasets as to whether discernable patterns exist that are suggestive of increased course choice opportunity holding a differentially higher appeal to female undergraduate engineering students. Results across 43 top-ranked engineering schools demonstrated a positive correlation between the median free elective credit hours offered to engineering students in a college and the college's percent of engineering bachelor's degrees that are awarded to women. Results also indicated that there is a positive correlation between the total number of opportunities engineering students in a college get to choose their courses and the college's percent of engineering bachelor's degrees that are awarded to women; the same was true for weighted choice. These results are intriguing and indicate that further work is called for in this area.

Significant correlations were also found between course choice opportunity and percentage female enrollments in chemical, civil, electrical, and mechanical engineering programs, as well as between course choice opportunity and the percent of bachelor's degrees awarded to women for electrical and mechanical engineering programs.

In a qualitative study that aimed to capture engineering disciplinary subcultures it was noted that, within the traditionally masculine culture of engineering education, disciplines vary in

how welcoming they are of women's participation (Godfrey, 2007). While chemical and materials engineering was found to have a culture that encompassed both masculine and feminine characteristics (which is reflected in comparatively higher percentage female enrollment), the electrical engineering culture was the most masculine (again, reflected in comparatively poor female enrollment) (Godfrey, 2007). With these findings in mind, the current quantitative exploratory study yielded a new hypothesis: that in more masculine programs, less popular with women (such as electrical or mechanical engineering), offering increased course choice opportunity in a given program may hold more potential to greatly impact female interest in that program.

The results from this preliminary study appear to be indicative of improved female enrollments corresponding to engineering program or college environments that are more autonomy-supportive of students in terms of comparatively higher course choice opportunities, but if these factors do actually correspond to one another, we still know nothing about *causation*. The results from this study included intriguing correlations that warrant more qualitative research to better understand the complex relationship between the choice opportunities these metrics probe at and the student experiences of those choices, with a differentiated look at the experiences of female students. This future work is necessary to ascertain whether and *how* engineering programs can work to attract and graduate more female students—and all students—by cultivating autonomy-supportive undergraduate educational experiences.

CHAPTER 6

CONCLUSIONS AND FUTURE WORK

Increasing Course Choice Opportunity in Engineering Education

This thesis explored the course choice opportunities and technical—non-technical coursework balance allocated to undergraduate engineering students in hundreds of diverse engineering degree programs across the country. The findings demonstrate that comparatively minimal course choice opportunity is prevalent in engineering degree programs. An overall national trend of course choice opportunity disparities exists between engineering and non-engineering students through the lens of each of the four course choice variables created for this dissertation. Previous work establishing autonomy as a basic human psychological need (Deci et al., 1991; Ryan and Deci, 2000) makes it logical to hypothesize that this mainstream low course choice opportunity culture in undergraduate engineering education is in conflict with students' psychological need to feel a sense of volition in their acts, and therefore is likely to have detrimental effects for students endeavoring to matriculate through engineering.

The old-guard engineering culture may lead us to believe that this is just "the way it is" in engineering and we must continue with the status-quo "survival of the fittest" method of tortuously churning engineering students through the low choice, overly technical degree program gauntlet, where only the toughest and most deserving students survive. And, some disciplines are finding it increasingly difficult to meet both technical and non-technical requirements for their discipline that they believe are necessary training for professionally licensed engineers with significant responsibilities for public safety and global sustainability within the decreasing credit hours being allocated to engineering degrees, and as-such choice is

getting squeezed out (ASCE Body of Knowledge, 2008). This work, however, finds any such notions about the incompatibility of course choice opportunity and engineering programs unfounded and demonstrates that this bleak course choice opportunity convention in undergraduate engineering education is not only unfair to students and unrealistic to ask of them, it also entirely *unnecessary* in terms of accreditation requirements. Exceptional accredited, prestigious, and specialized undergraduate engineering degree programs exist that are autonomy-supportive and provide substantial course choice opportunities to students, demonstrating exciting possibilities for reworking the design of undergraduate engineering degree programs to better support students' psychological needs.

The engineering students enrolled in the highlighted exceptional programs with greater course choice opportunities experience the freedom to choose more courses, making their undergraduate academic experiences more congruent with those of their non-engineering peers on campus in terms of their ability for curricular exploration. The existence of these programs confirms that highly-ranked EAC ABET-accredited specialized engineering degree programs and significant course choice opportunity *are* compatible. It is not only possible to afford engineering undergraduates with both, but —through the lens of Self Determination Theory— it may even be *essential*. The standout engineering discipline degree programs from this study with the highest course choice variable values demonstrate tangible possibilities for re-structuring the design of undergraduate engineering degree programs to better support students' need for autonomy by way of increased course choice opportunities.

The psychological impact(s) of the current mainstream low course choice opportunity culture and high course choice opportunity disparity on undergraduate engineering students remains unknown, but SDT research is clear—autonomy-unsupportive educational environments

not only miss out on the profound benefits of mindfully offering students choices, but stand to hinder developmental processes, and foster feelings of alienation, ill-being, and demotivation (Deci et al., 1991; Ryan and Deci, 2000). Still unknown is whether course choice opportunities can satisfy undergraduate students' psychological need for autonomy in the same way that has been demonstrated for the power of choice in classroom learning activity outcomes (Deci et al., 1991; Jones, 2009; Jones and Wilkins, 2013; Ryan and Deci, 2000; Vanasupa, Stolk, and Harding, 2010; Vanasupa, Stolk, and Herter, 2009), and if so, could yield tangible beneficial educational outcomes such as broadening participation, increased enrollment, and improved retention and graduation rates in engineering education. These topics will be explored in future research.

It is reasonable to hypothesize that more restrictive engineering programs with less student choice might have lower retention of engineering students who desire more autonomy and choice. At institutions where non-engineering degrees offer significantly more choice, undergraduate students desirous of self-determination might be attracted to those non-engineering programs. In addition, programs that offer *more* choice (particularly free electives) may have higher in-migration of students from non-engineering disciplines, since these programs may still allow students to graduate on-time due to the ability to transfer in their coursework from other disciplines. These hypotheses have not yet been tested. It further remains to seen whether certain *types* of course choice opportunities yield greater psychological benefits (such as more free electives versus more total course choice opportunities versus some combination, etc.) and would be more effective at improving educational outcomes.

It is important to recall that overwhelming choice and freedom is also not psychologically preferable (Schwartz, 2004); thus, it is important to find the point of *optimal* course choice

opportunity. Further research is needed in order to make more specific recommendations about the most impactful types of course choice opportunities to offer engineering students.

The Intentional Diversification of Technical—Non-Technical Coursework Allocation

Findings from this thesis also demonstrate that a wide range of technical—non-technical balance exists across the nation's engineering degree programs, with the required technical and non-technical credit hours varying across the studied degree programs at most by what translates to almost an entire *year* (out of a four-year program) during which some students would exclusively take technical courses, while others exclusively take non-technical courses, but all graduate with top-ranked ABET-accredited specialized engineering degrees. It is evident from the range of credit hour requirements (seen for both technical and non-technical coursework and across programs) that widespread consensus does not exist amongst engineering educators regarding the appropriate allocation of technical versus non-technical coursework for a specialized engineering undergraduate education. Also clear is that there are substantially divergent interpretations amongst engineering educators as to what constitutes adequate "general education" for an engineer. Surely, engineering students enrolled across the studied degree programs have differing academic experiences and graduate with diverse skillsets.

These high-level quantitative snapshots of course allocations for dozens of specialized engineering programs nationwide are clues as to where respective engineering program's educational priorities lie—and it would seem that these priorities differ. However, this wide range of curricular allocations and differing priorities is not obviously presented to prospective engineering students and could therefore have potentially injurious effects on the recruitment and

retention of undergraduates who may find themselves enrolled in engineering programs that do not reflect the curricular experience they thought they signed up, nor are well-matched for their career aspirations.

Today's engineering graduates go on to diverse career paths, in both what are traditionally categorized as "technical" and "non-technical" fields, requiring a blend of both skillsets in differing proportions. Engineering graduates are working in countless non-STEM fields such as architecture, arts and entertainment, business, education, health care, non-STEM management, sales, and social services, in addition to careers in math, science, and engineering (United States Census Bureau, 2014). And, our society is well served by technically-literate graduates working in fields that are not traditionally thought of as technical, such as journalism, law, and politics.

Intentionally Inviting Diverse Technical and Non-Technical Course Allocations into an Engineering College

So, where to go from here? If we are to make use of the range of possible technical and non-technical course allocations highlighted by this study, we must ensure that the balance is *purposeful*. As an example, the University of Colorado Boulder (CU Boulder) offers (among other accredited engineering programs) traditional aerospace, architectural, civil, environmental, electrical, and mechanical engineeirng degree programs, each with comparatively very high technical credit hour requirements, minimal nontechnical credit hour requirements of 18 credit hours, and several to zero free elective credit hours. But beginning in 2013, CU Boulder *also* offers the design-focused "Engineering Plus" (e+) bachelors of science degree program that makes a more balanced technical and non-technical curriculum accessible to students with diverse career interests desiring a customizable educational experience. Students in this degree

program complete a common design-focused engineering *core* and choose an engineering *emphasis* in either aerospace, architectural, civil, environmental, electrical, or mechanical engineering. Students are required to take 81 normalized credit hours of technical coursework (considerably less than other engineering degree programs in the college that commonly require well over 100) and the same 18 credit hours of non-technical coursework as their engineering peers in other disciplines. In addition, however, e+ students have 12 credit hours that they can devote to a technical or non-technical *concentration* in an area of personal interest, and up to 19 credit hours of free electives that they can further devote to the pursuit of their choice.

The e+ program provides an alternative to the other highly technically-focused degree programs in the college for students with broad interests and career aspirations that would be poorly served by the more traditional programs. An added benefit is that students are provided with (comparatively) more opportunities to choose their courses—something commonly lacking in many undergraduate engineering programs (Forbes, Bielefeldt, and Sullivan, 2015; Forbes et al., 2015). The e+ program plans to seek ABET-accreditation in 2017.

Intentionally inviting the *spectrum* of differing proportions of technical and non-technical coursework into engineering programs housed in the same college in this way expands both what is offered to students and how we can serve them. An engineering student interested in leading international development projects, for example, might be well served in the e+ program getting a solid engineering education while also balancing that preparation with courses in the language, history, and culture specific to the area in which he or she hopes to work. Conversely, another student interested in a career as a technically-focused aerospace engineer working in industry might find the 18 credit hours of "general eduction" adequate and would be better served by the traditional, more technically-focused, aerospace engineering degree.

It is recommended that colleges exclusively offering highly technically focused engineering degree programs (such as those requiring over 100 normalized technical hours) consider implementing their own version of an e+ program, in some way expanding their degree program offerings to also include selections that mimic the higher non-technical course allocations of other programs detailed in this study. Providing students with both options can serve to broaden engineering participation to students with career interests better served by a more balanced engineering curriculum and begin (or expand) an intentional conversation about the differences in course allocations for various engineering programs and the students that are best served by those allocations.

And so, we have an opportunity to make great use of the range of possible technical and non-technical course allocations highlighted by this study, by making this range purposeful and initiating an open dialogue with students around curricular balance opportunities. If the community of engineering educators becomes more intentional and forward-thinking about these differing curricular allocation and balance opportunities, this wide range of technical—non-technical balance that now seems unsettling (if inadvertent) can morph into a great asset of differentiated education to better serve society and students. Specific recommendations were made for engineering schools to intentionally invite the spectrum of differing proportions of technical and non-technical coursework into engineering programs housed in the same college, expanding the balance that is offered to students and, by extension, affording them with more choice.

Closing Words

If we are to broaden participation and improve our ability to attract and retain men and women in undergraduate engineering programs, we must have a willingness to try novel educational approaches. This thesis presents an opportunity to expand the traditional conception of undergraduate engineering degree program design to better serve students in concert with their innate psychological needs and properly educate them for increasingly diverse career paths via more flexible degree programs. A conscious cultivation of program environments to nurture students' innate need for autonomy through a purposeful allocation of technical and non-technical degree program content that responsibly educates the engineers of our future will be fundamental to this renovation of undergraduate engineering education. This recommended overhauling of engineering education program design must take into account the psychological and developmental needs of students *in concert with* a foundation of ethical, demanding, effective, and reputable engineering education.

This thesis has provided actionable recommendations for engineering educators motivated to stimulate change in both low course choice opportunity programs and/or programs lacking pathways for increased non-technical coursework opportunities. This work is a call to action for engineering educators, an appeal to rework undergraduate engineering degree program designs to reflect both the psychological needs of students and the evolving—and expanding—role of the engineer in society.

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APPENDIX A: COURSE CHOICE OPPORTUNITIES FOR DOCTORAL VERSUS NO DOCTORAL UNIVERSITIES

Figure A.1: Total Free Elective Credit Hours for Doctoral versus No Doctoral universities across four engineering program-types.

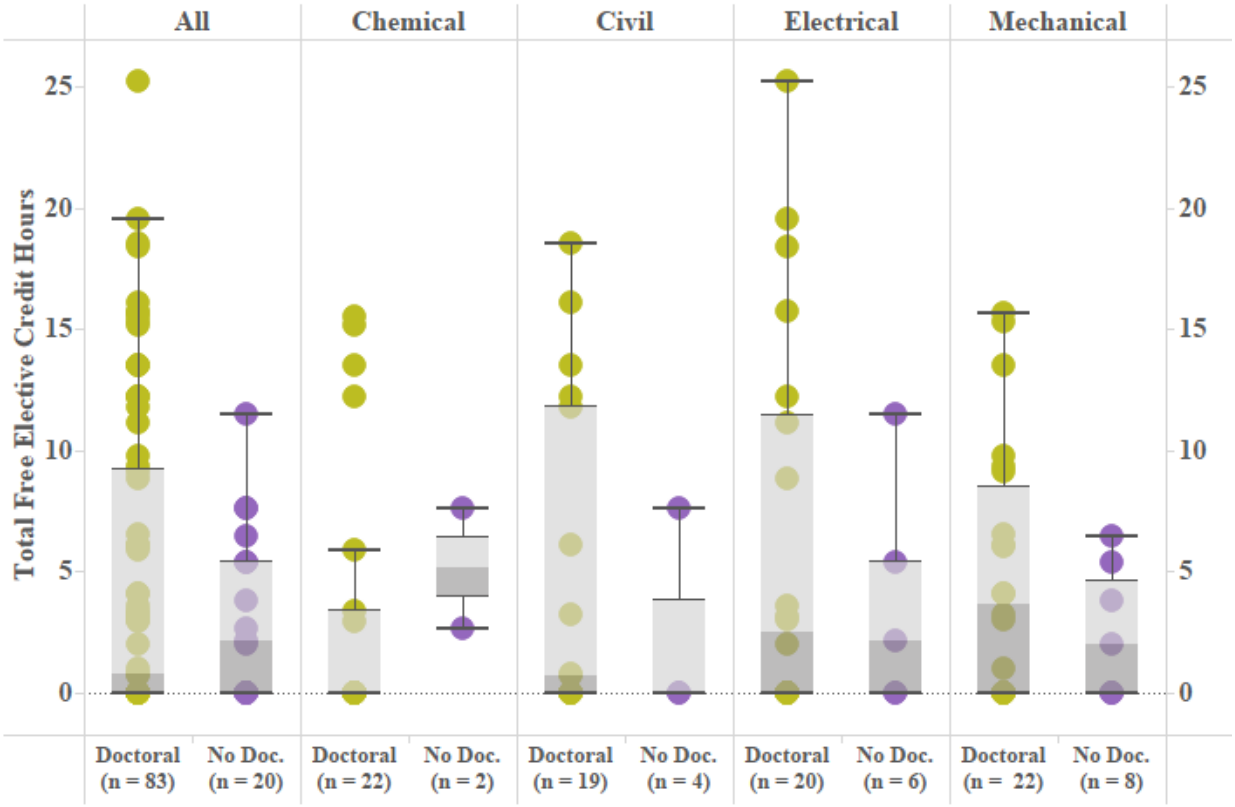


Table A.1. Median Total Free Elective Credit Hour values and Mann-Whitney U p-values for Doctoral versus No Doctoral universities across four engineering program-types.

Engineering Program-Type				
All	**Chemical**	**Civil**	**Electrical**	**Mechanical**
$\tilde{x}_{\text{Doc}} = 0.8$	$\tilde{x}_{\text{Doc}} = 0.0$	$\tilde{x}_{\text{Doc}} = 0.7$	$\tilde{x}_{\text{Doc}} = 2.5$	$\tilde{x}_{\text{Doc}} = 3.7$
$\tilde{x}_{\text{No Doc}} = 2.2$	$\tilde{x}_{\text{No Doc}} = 5.2$	$\tilde{x}_{\text{No Doc}} = 0.0$	$\tilde{x}_{\text{No Doc}} = 2.2$	$\tilde{x}_{\text{No Doc}} = 2.0$
p = 0.833	**p = 0.500**	**p = 0.534**	**p = 0.776**	**p = 0.372**

Figure A.2: Weighted Choice Score for Doctoral versus No Doctoral universities across four engineering program-types.

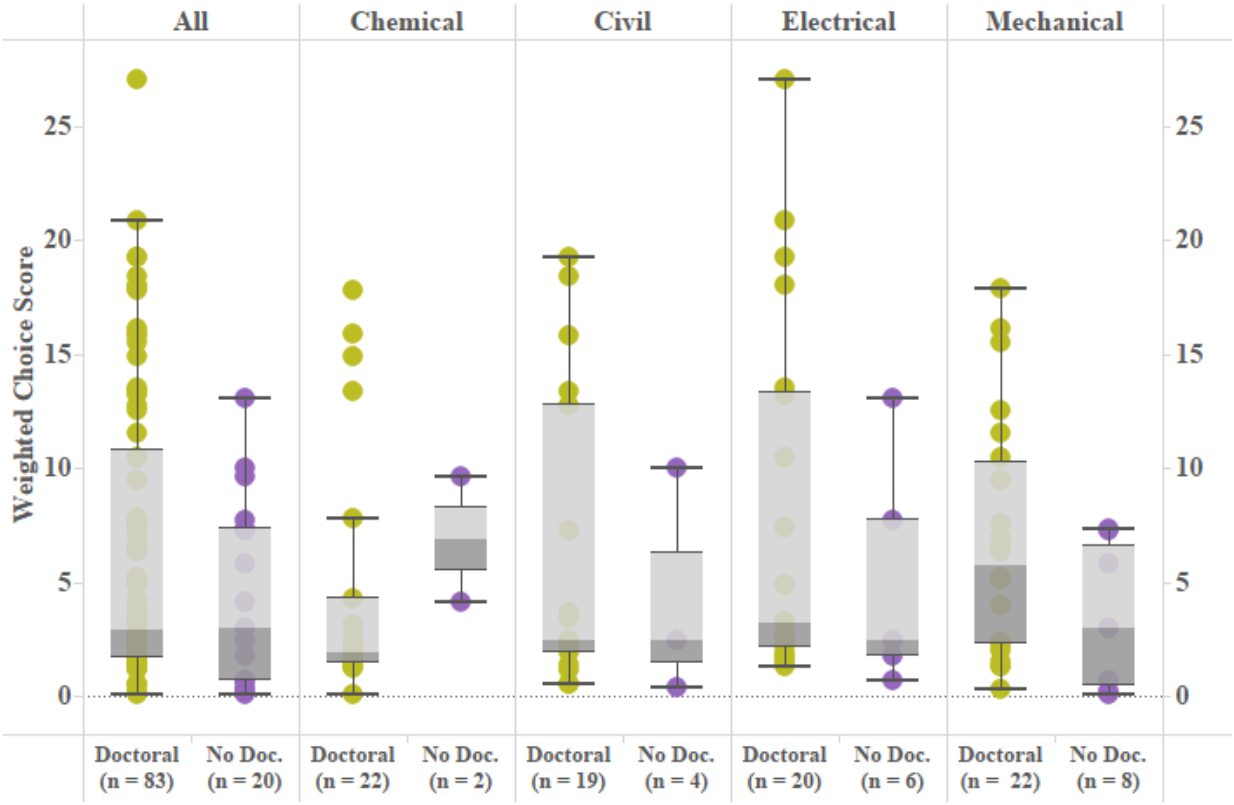


Table A.2. Median Weighted Choice Score values and Mann-Whitney U p-values for Doctoral versus No Doctoral universities across four engineering program-types.

Engineering Program-Type				
All	**Chemical**	**Civil**	**Electrical**	**Mechanical**
$\tilde{x}_{\text{Doc}} = 2.9$ $\tilde{x}_{\text{No Doc}} = 3.0$ **p = 0.372**	$\tilde{x}_{\text{Doc}} = 1.9$ $\tilde{x}_{\text{No Doc}} = 6.9$ **p = 0.855**	$\tilde{x}_{\text{Doc}} = 2.5$ $\tilde{x}_{\text{No Doc}} = 2.5$ **p = 0.634**	$\tilde{x}_{\text{Doc}} = 3.2$ $\tilde{x}_{\text{No Doc}} = 2.4$ **p = 0.415**	$\tilde{x}_{\text{Doc}} = 5.8$ $\tilde{x}_{\text{No Doc}} = 3.0$ **p = 0.139**

Figure A.3: Average Choice per Opportunity for Doctoral versus No Doctoral universities across four engineering program-types.

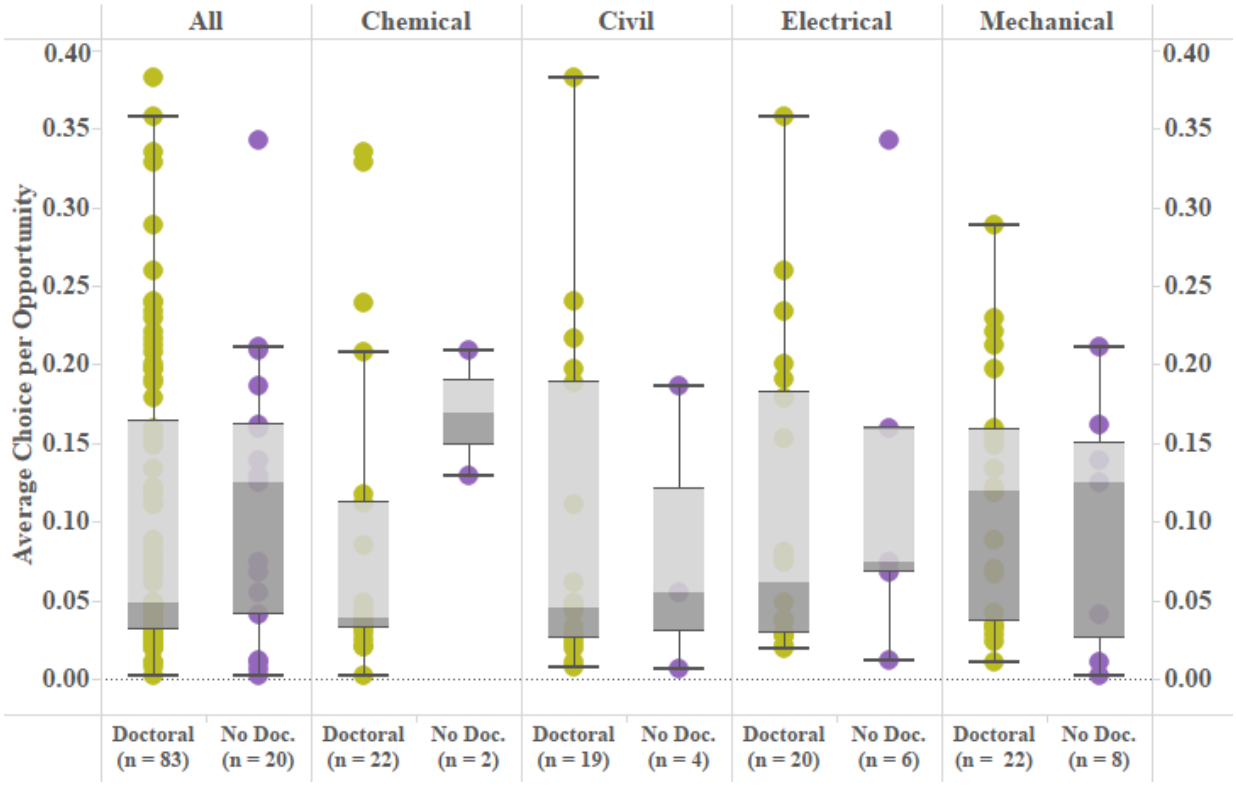


Table A.3. Median Average Choice per Opportunity values and Mann-Whitney U p-values for Doctoral versus No Doctoral universities across four engineering program-types.

Engineering Program-Type				
All	**Chemical**	**Civil**	**Electrical**	**Mechanical**
$\tilde{x}_{\text{Doc}} = 0.05$ $\tilde{x}_{\text{No Doc}} = 0.12$ **p = 0.707**	$\tilde{x}_{\text{Doc}} = 0.04$ $\tilde{x}_{\text{No Doc}} = 0.17$ **p = 0.268**	$\tilde{x}_{\text{Doc}} = 0.05$ $\tilde{x}_{\text{No Doc}} = 0.05$ **p = 0.750**	$\tilde{x}_{\text{Doc}} = 0.06$ $\tilde{x}_{\text{No Doc}} = 0.07$ **p = 0.785**	$\tilde{x}_{\text{Doc}} = 0.12$ $\tilde{x}_{\text{No Doc}} = 0.12$ **p = 0.557**

APPENDIX B: TECHNICAL AND NON-TECHNICAL CREDIT HOURS FOR FOUR ENGINEERING PROGRAM-TYPES OFFERED AT 15 UNIVERSITIES

Figure B.1: Total required technical credit hours for four engineering program-types offered at 15 universities.

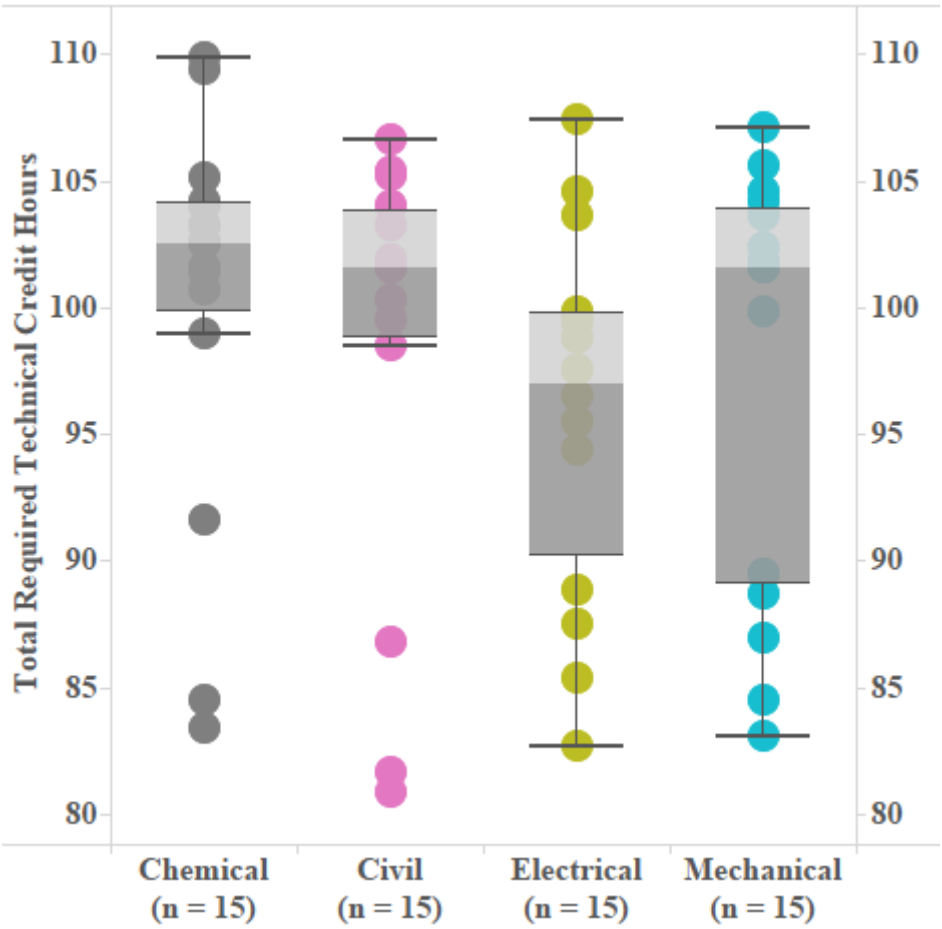


Table B.1: Median total required technical credit hours and Friedman ANOVA p-value for four engineering program-types offered at 15 universities.

Engineering Program-Type				Friedman ANOVA
Chemical	**Civil**	**Electrical**	**Mechanical**	
$\tilde{x}_{Chem} = 102.5$	$\tilde{x}_{Civil} = 101.6$	$\tilde{x}_{Elect} = 97.0$	$\tilde{x}_{Mech} = 101.6$	**p = 0.135**

Figure B.2: Total required non-technical credit hours for four engineering program-types offered at 15 universities.

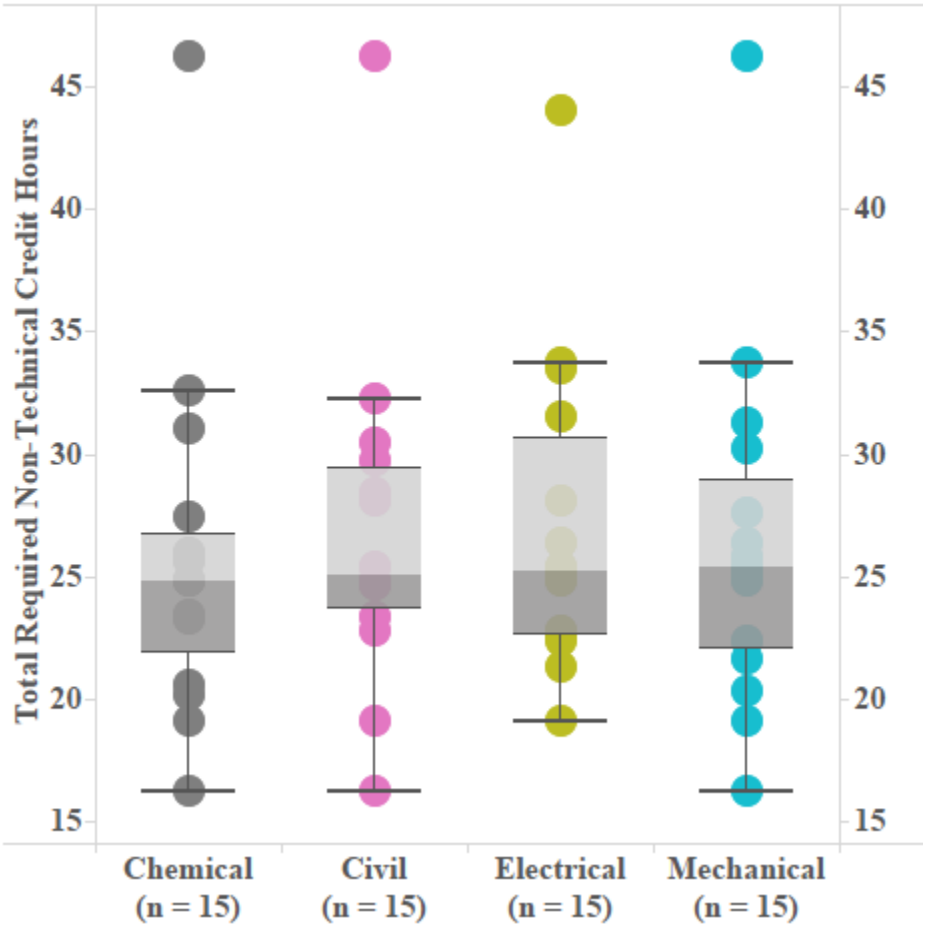


Table B.2: Median total required non-technical credit hours and Friedman ANOVA p-value for four engineering program-types offered at 15 universities.

Engineering Program-Type				Friedman ANOVA
Chemical	**Civil**	**Electrical**	**Mechanical**	
$\tilde{x}_{\text{Chem}} = 24.9$	$\tilde{x}_{\text{Civil}} = 25.1$	$\tilde{x}_{\text{Elect}} = 25.2$	$\tilde{x}_{\text{Mech}} = 25.4$	**p = 0.644**

Figure B.3: Total possible non-technical credit hours for four engineering program-types offered at 15 universities.

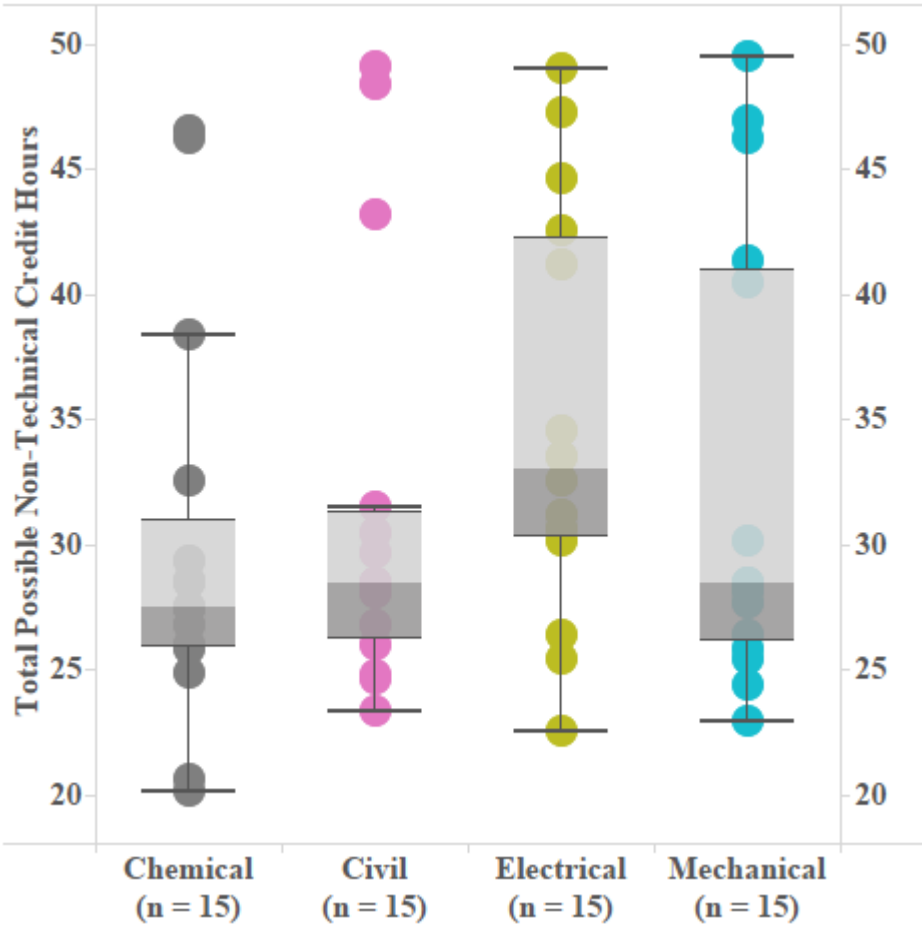


Table B.3: Median total possible non-technical credit hours and Friedman ANOVA p-value for four engineering program-types offered at 15 universities.

Engineering Program-Type				Friedman ANOVA
Chemical	**Civil**	**Electrical**	**Mechanical**	
$\tilde{x}_{\text{Chem}} = 27.5$	$\tilde{x}_{\text{Civil}} = 28.4$	$\tilde{x}_{\text{Elect}} = 33.0$	$\tilde{x}_{\text{Mech}} = 28.4$	**p = 0.100**

APPENDIX C: TECHNICAL AND NON-TECHNICAL CREDIT HOURS FOR FOUR ENGINEERING PROGRAM-TYPES AT DOCTORAL VERSUS NO DOCTORAL UNIVERSITIES

Figure C.1: Total required technical credit hours for Doctoral versus No Doctoral universities across four engineering program-types.

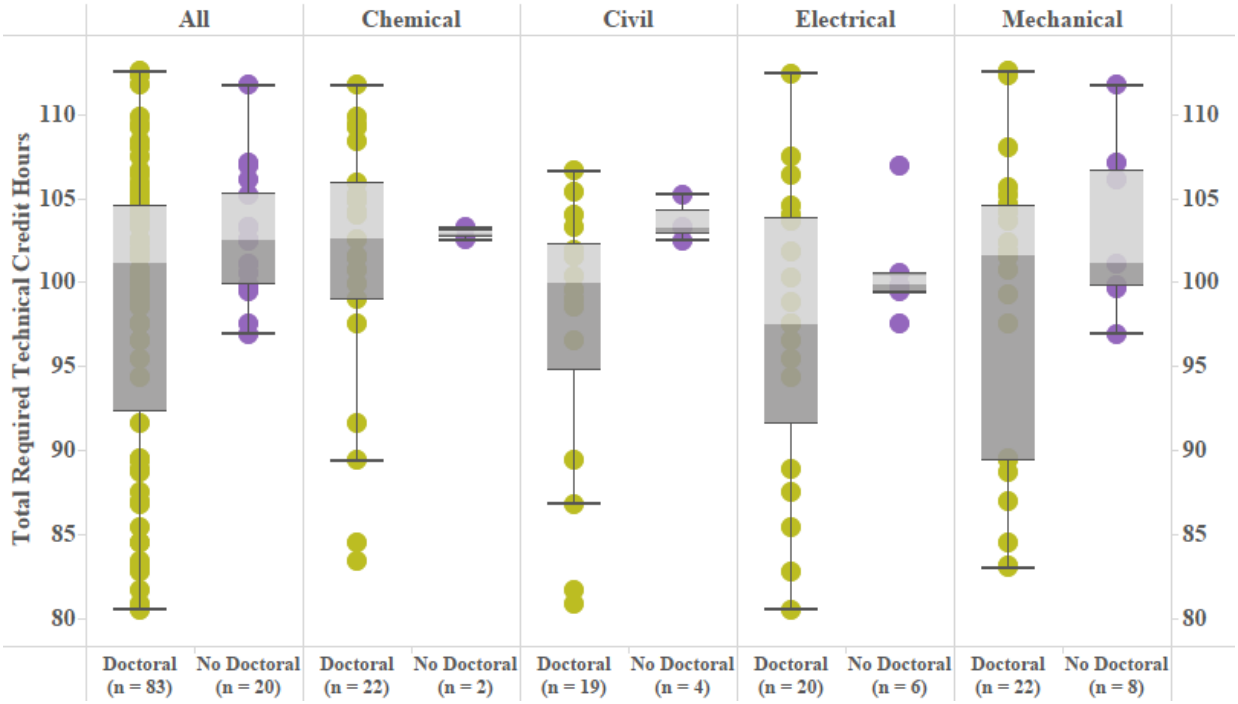


Table C.1. Median total required technical credit hours and Mann-Whitney U p-values for Doctoral versus No Doctoral universities across four engineering program-types.

Engineering Program-Type				
All	**Chemical**	**Civil**	**Electrical**	**Mechanical**
$\tilde{x}_{\text{Doc}} = 101.1$ $\tilde{x}_{\text{No Doc}} = 102.5$ **p = 0.203**	$\tilde{x}_{\text{Doc}} = 102.6$ $\tilde{x}_{\text{No Doc}} = 102.9$ **p = 1.000**	$\tilde{x}_{\text{Doc}} = 99.9$ $\tilde{x}_{\text{No Doc}} = 103.2$ **p = 0.129**	$\tilde{x}_{\text{Doc}} = 97.5$ $\tilde{x}_{\text{No Doc}} = 99.9$ **p = 0.355**	$\tilde{x}_{\text{Doc}} = 101.6$ $\tilde{x}_{\text{No Doc}} = 101.1$ **p = 0.429**

Figure C.2: Total required non-technical credit hours for Doctoral versus No Doctoral universities across four engineering program-types.

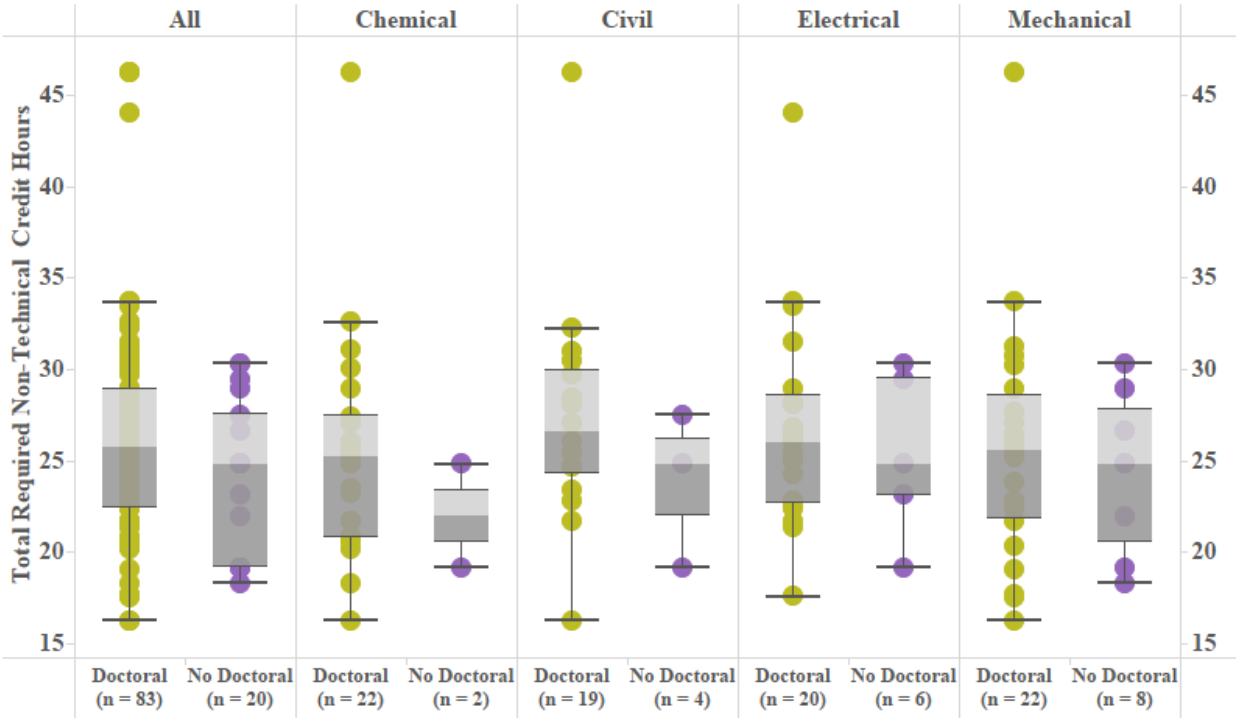


Table C.2. Median total required non-technical credit hours and Mann-Whitney U p-values for Doctoral versus No Doctoral universities across four engineering program-types.

Engineering Program-Type				
All	**Chemical**	**Civil**	**Electrical**	**Mechanical**
$\tilde{x}_{\text{Doc}} = 25.7$ $\tilde{x}_{\text{No Doc}} = 24.8$ **p = 0.293**	$\tilde{x}_{\text{Doc}} = 25.2$ $\tilde{x}_{\text{No Doc}} = 22.0$ **p = 0.324**	$\tilde{x}_{\text{Doc}} = 26.5$ $\tilde{x}_{\text{No Doc}} = 24.8$ **p = 0.398**	$\tilde{x}_{\text{Doc}} = 26.0$ $\tilde{x}_{\text{No Doc}} = 24.8$ **p = 0.776**	$\tilde{x}_{\text{Doc}} = 25.6$ $\tilde{x}_{\text{No Doc}} = 24.8$ **p = 0.740**

Figure C.3: Total possible non-technical credit hours for Doctoral versus No Doctoral universities across four engineering program-types.

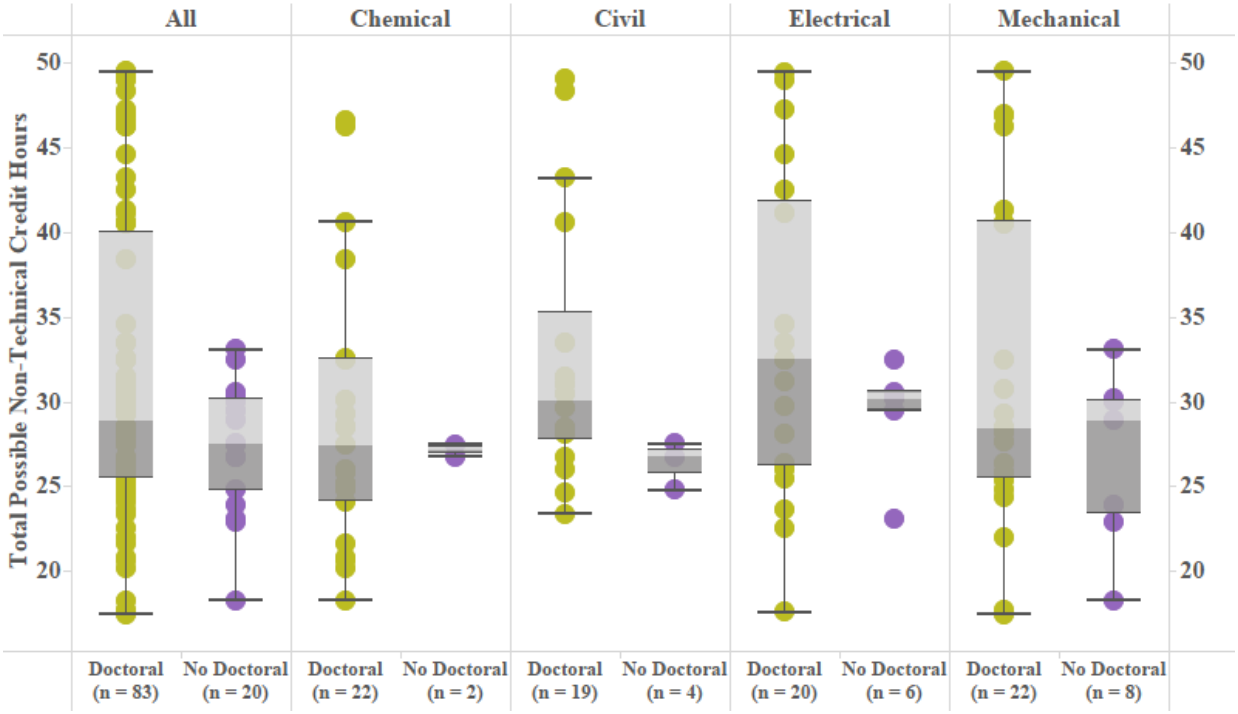
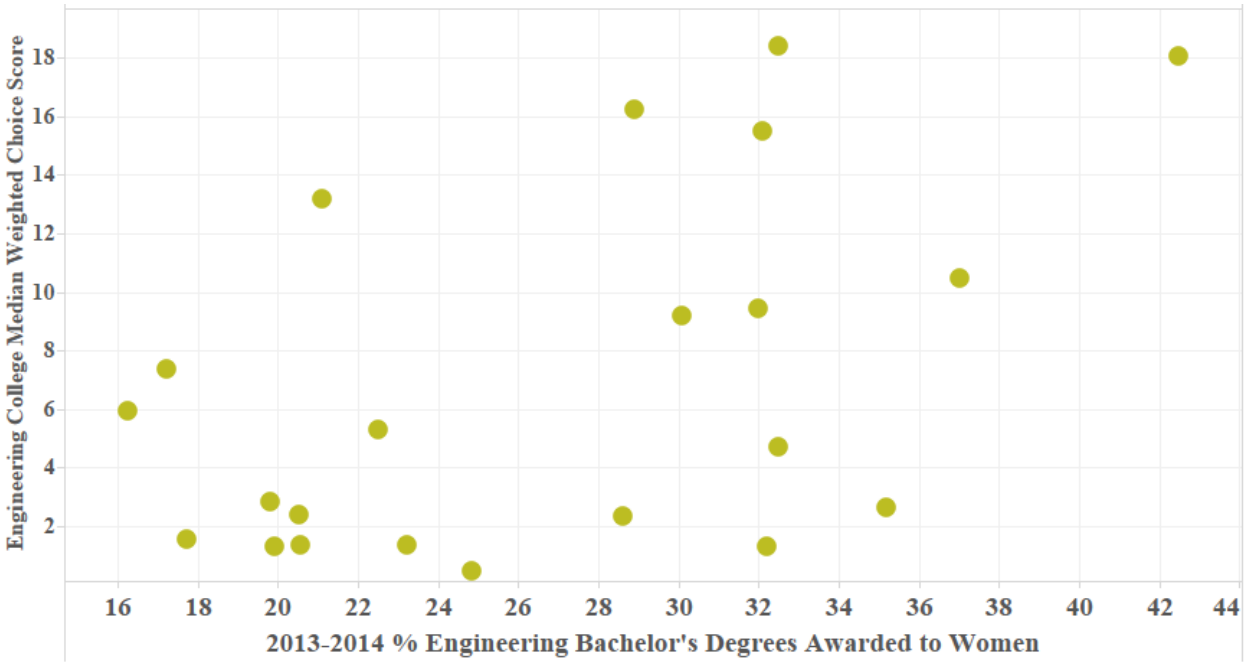


Table C.3. Median total possible non-technical credit hours and Mann-Whitney U p-values for Doctoral versus No Doctoral universities across four engineering program-types.

Engineering Program-Type				
All	**Chemical**	**Civil**	**Electrical**	**Mechanical**
$\tilde{x}_{\text{Doc}} = 28.9$ $\tilde{x}_{\text{No Doc}} = 27.5$ **p = 0.194**	$\tilde{x}_{\text{Doc}} = 27.4$ $\tilde{x}_{\text{No Doc}} = 27.1$ **p = 1.000**	$\tilde{x}_{\text{Doc}} = 30.1$ $\tilde{x}_{\text{No Doc}} = 26.8$ **p = 0.129**	$\tilde{x}_{\text{Doc}} = 32.5$ $\tilde{x}_{\text{No Doc}} = 30.2$ **p = 0.373**	$\tilde{x}_{\text{Doc}} = 28.4$ $\tilde{x}_{\text{No Doc}} = 28.9$ **p = 0.414**

APPENDIX D: COURSE CHOICE METRICS VERSUS ENGINEERING BACHELOR'S DEGREES AWARDED TO WOMEN

Figure D.1: Median Weighted Choice Score by engineering college versus the 2013-2014 percent of college engineering bachelor's degrees awarded to women for 22 Doctoral Schools.



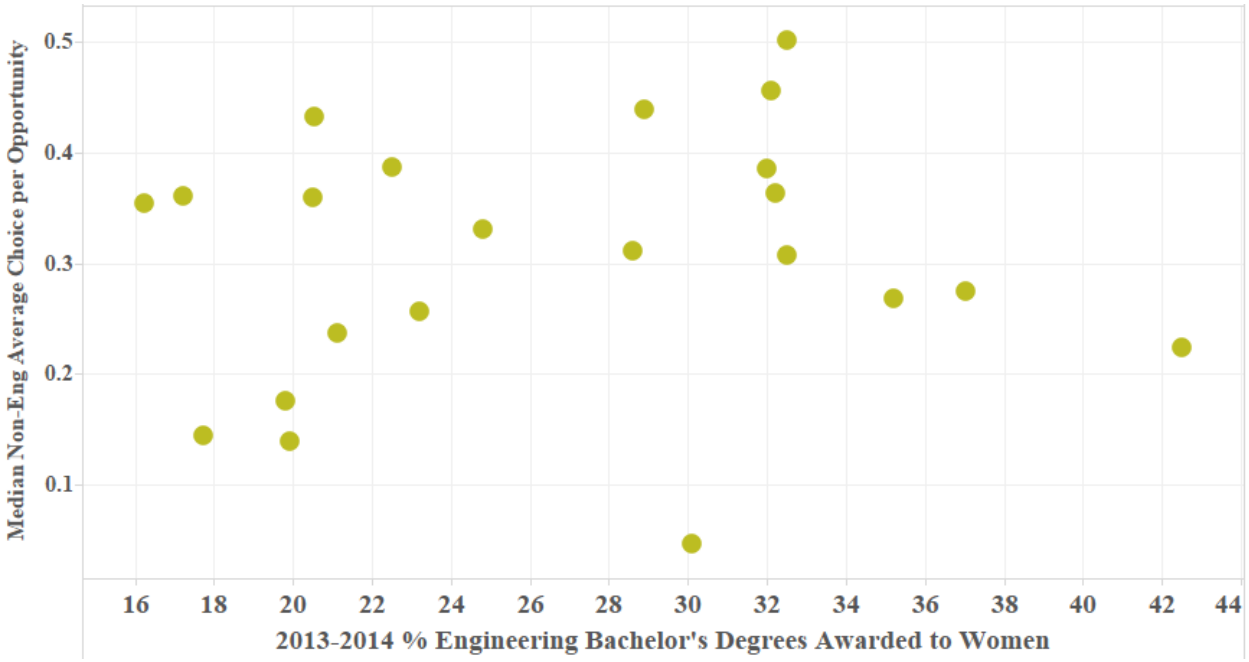
- The Spearman's rho correlation coefficient for Doctoral institutions was 0.390, which is statistically significant at the $\alpha = 0.05$ level.

Figure D.2: Median Weighted Choice Score by engineering college versus the 2013-2014 percent of college engineering bachelor's degrees awarded to women for 21 No Doctoral Schools.



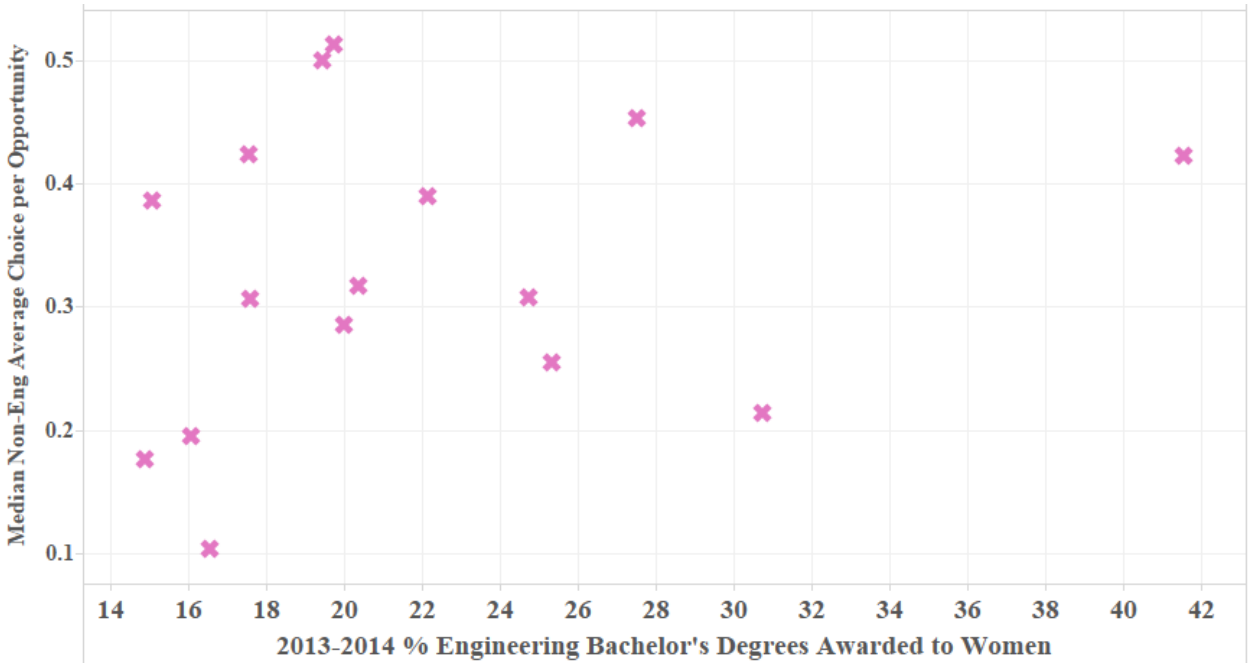
- The Spearman's rho correlation coefficient for No Doctoral institutions was 0.418, which is statistically significant at the $\alpha = 0.05$ level.

Figure D.3: Median Average Choice per Opportunity value by engineering college versus the 2013-2014 percent of college engineering bachelor's degrees awarded to women for 22 Doctoral Schools.



- The Spearman's rho correlation coefficient for Doctoral institutions was 0.176, which is not statistically significant.

Figure D.4: Median Average Choice per Opportunity value by engineering college versus the 2013-2014 percent of college engineering bachelor's degrees awarded to women for 21 No Doctoral Schools.



- The Spearman's rho correlation coefficient for No Doctoral institutions was 0.444, which is statistically significant at the $\alpha = 0.05$ level.

APPENDIX E: COMPARING CORRELATIONS ACROSS ENGINEERING DISCIPLINES

Correlation tests were run on the aggregated discipline-specific data for chemical, civil, electrical, and mechanical engineering (n = 4) including 1) the national percentage of bachelor's degrees awarded to women (by discipline) and 2) the median percentage (by discipline) of bachelor's degrees awarded to women for the programs included in this study versus the previously reported Spearman's rho *correlation coefficients* (reported in Tables 5.3 – 5.6) from the analyses between the percentage of bachelor's degrees awarded to women (by discipline, for the 19 – 22 degree programs included in this study, respectively) versus their choice variable values (for Total Free Elective Credit Hours, Total Choice Count, Weighted Choice Score, and Average Choice per Opportunity, respectively). The results from this analysis are presented in Table E.1.

Table E.1: Spearman's rho correlation coefficients for aggregated chemical, civil, electrical, and mechanical engineering program data.

	Nation-wide % Bach. Degrees to Women	Median % Bach. Degrees to Women for the Studied Programs	Corr. % Bach. Degrees to Women v. *Total Free Elective Credit Hours*	Corr. % Bach. Degrees to Women v. *Total Choice Count*	Corr. % Bach. Degrees Awarded to Women v. *Weighted Choice Score*	Corr. % Bach. Degrees to Women v. *Average Choice per Opp.*
Nation-wide % Bach. Degrees to Women	1.000	**1.000***	-.800	-.600	-.600	-.800
Median % Bach. Degrees to Women for the Studied Programs	**1.000***	1.000	-.800	-.600	-.600	-.800
Corr. % Bach. Degrees to Women v. *Total Free Elective Credit Hours*	-.800	-.800	1.000	.800	.800	**1.000***
Corr. % Bach. Degrees to Women v. *Total Choice Count*	-.600	-.600	.800	1.000	**1.000***	.800
Corr. % Bach. Degrees Awarded to Women v. *Weighted Choice Score*	-.600	-.600	.800	**1.000***	1.000	.800
Corr. % Bach. Degrees to Women v. *Average Choice per Opp.*	-.800	-.800	**1.000***	.800	.800	1.000

Note: Spearman's rho values equal to 1.000 have a two-tailed level of significance at an α = 0.10 level for a sample size of 4 (Sheskin, 2003).

Due to the small sample size (n=4) provided by data from four engineering disciplines for this analysis, only Spearman's rho values equal to 1.000 are indicative of statistical significance, and only at an $\alpha = 0.10$ (Sheskin, 2003). Research involving larger sample size will provide more definitive information on the true nature of the relationships investigated here and allow for more specific conclusions to be drawn.