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# The Choice Opportunity Disparity: Exploring Curricular Choice Opportunities for Engineering vs. Non-Engineering Majors

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Jacquelyn Sullivan is founding co-director of the General Engineering Plus degree program in the University of Colorado Boulder's College of Engineering and Applied Science. The newly-launched, design-based, "design-your-own" flexible GE+ engineering degree was initially created as the "home" for CU Teach Engineering, a unique initiative to produce secondary science or math teachers through a design-based engineering degree. With the aim of enhancing curricular choice as a means to broaden participation among who chooses to attend engineering college, the GE+ degree was quickly expanded to provide a strong analytical, engineering-based platform for students driven to chart their own educational path. Sullivan was conferred as an ASEE Fellow in 2011 and was awarded NAE's 2008 Gordon Prize for Innovation in Engineering and Technology Education.

# The Choice Opportunity Disparity: Exploring Curricular Choice Opportunities for Engineering vs. Non-Engineering Majors


## Abstract

Educational environments that support autonomy have been shown to foster self-motivation, increased engagement, higher-quality learning, and personal well-being[4,5,6]—all outcomes that could positively impact access and retention in engineering programs. Increasing course choice opportunities for students seeking an engineering degree could therefore encourage them to meet their innate psychological need for autonomy within the context of an engineering education and possibly benefit educational and program outcomes.

This preliminary study explores the extent of curricular choice that undergraduate students encounter in working towards engineering degrees, compared to their non-engineering peers on campus. The course choices that students are given the autonomy to make while earning ABET-accredited engineering degrees in various disciplines are compared to those of students earning degrees in physics, chemistry, math, economics and psychology. "Choice Values" for degree programs at five regionally diverse universities are presented, including both public and private institutions, a large research university, a small liberal arts college and a historically black college & university (HBCU).

For the purposes of this study, Choice Value is a quantified representation of the aggregate curricular choice opportunity for a given degree program, and is a function of total course choice opportunities, the proportion of degree credit hours that provide curricular choice, and the number of courses from which students may choose. Choice Values were determined using the published curriculum in the university catalogs, as well as counts for the number of individual course options for each choice opportunity. Choice opportunity examples include menus of course options, technical electives, humanities and social science electives, and free electives.

Findings reveal a significant course choice opportunity disparity between engineering and non-engineering students at the five universities studied. The differentially limited curricular choices available to engineering students across all five universities and degree programs included in the study are revealed. Engineering degree program Choice Values were an average of more than 17 times fewer than non-engineering degree program Choice Values, with a median value of 4.7 and a range of 1.8 to 96.1 times lower Choice Values in engineering. Engineering degree programs allocated an average of 4.3% of total degree credit hours to free electives, compared to 19.8% of total degree credit hours for non-engineering degree programs included in the study.

The comparatively dismal curricular course opportunities available to students pursuing engineering degrees leads to the question of how degree programs might provide more course choice opportunities, and if doing so might positively impact efforts at broadening participation in engineering enrollments and improve graduation rates. The General Engineering Plus (GE+) degree program, a new (2013) undergraduate degree program in the College of Engineering and Applied Science (CEAS) at the University of Colorado Boulder is presented. The GE+ degree program combines interdisciplinary hands-on engineering design plus an engineering emphasis with a student-chosen technical or non-technical concentration, providing students with degrees

of curricular choice previously unprecedented in the college's engineering programs, a Choice Value of 405.3 compared to the average Choice Value for CU Boulder's accredited engineering degree programs of 155.7. The GE+ program plans to seek accreditation under ABET's general engineering program criteria.

**Background**

In the 2005 publication, *Educating the Engineer of* 2020, the National Academy of Engineering recommended 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."[1] The American Society of Mechanical Engineers (ASME) Vision 2030 Task Force echoed this recommendation and named "*increased curricular flexibility*" as one of seven recommended actions intended to strengthen undergraduate mechanical engineering education.[2] Developmentally, infusing engineering curriculum with flexibility makes sense, considering "most 18- to 24-year-olds significantly redefine their self-identities, a process that involves exploring many factors including gender role identity, racial identity, social group identity, and professional identity."[3]

From a psychological standpoint, curricular 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*.[4, 5] Autonomy refers to "being self-initiating and self-regulating of one's own actions."[5] 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."[4] 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."[4] Failure to support the needs for competence, relatedness and autonomy "contributes to alienation,[4] ill-being,[4] demotivation,[5] and impairment of developmental processes.[5] "When people have no choice, life is almost unbearable."[7]

But, providing choices for students can be either motivating or demotivating; in order to realize the benefits of choice, it must be done right.[7] The psychologically paralyzing effect of an overload of meaningless choices is evident in countless increasingly complex consumer decisions.[7] However choice has been shown to be motivating in educational settings and can also enhance learning and well-being[4,5,8,9] when "the options are relevant to the students' interests and goals (autonomy support), are not too numerous or complex (competence support), and are congruent with the values of the students' culture (relatedness support)."[6] Thus, 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,"[5] increased engagement and higher-quality learning.[4,5]

These SDT research findings could hold untapped, important information about the potential to impact engineering students' academic motivation, commitment and performance by intentionally fostering educational environments that are supportive of their psychological needs. Educational environments (such as engineering colleges and/or engineering degree programs) desiring to reap these benefits can only do so if they are "autonomy supportive," making it

possible for students to satisfy their innate psychological need for autonomy by encouraging self-determination and providing choices. Systemic changes to undergraduate engineering curriculum and education—such as integrating more curricular choice opportunities and self-direction—could impact access, retention and numerous other beneficial educational outcomes seen in previous SDT research studies.

## Research Question

The SDT research findings lead to the big question of whether increasing course choice opportunities for students seeking engineering degrees 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. To begin answering this overarching question, however, we must first understand the state of curricular choice in undergraduate degree programs. This study aims to begin this work by asking, *how does the amount of curricular choice undergraduate engineering students encounter in working towards their engineering degrees compare to that of their non-engineering peers on campus?*

## Methods

A quantitative analysis was performed to explore the amount of curricular choice undergraduate students encounter in working towards engineering degrees compared to their non-engineering peers on campus. Five regionally diverse universities were chosen for this study, including both public and private institutions, a large research university, a small liberal arts college, and a HBCU, each of different size and Carnegie Classification[11] (see Table 1).

**Table 1.** University population and type included in the study.

| Institution | Type | Carnegie Classification[11] | U-Grad Univ. Pop. 2013 | FT U-Grad Eng Pop. 2013 |
|---|---|---|---|---|
| **U. of Colorado Boulder** | public | RU/VH<br>Research University<br>(very high research activity) | 26,000 | 3,700 |
| **University B** | public | RU/H<br>Research University<br>(high research activity) | 4,300 | 4,000 |
| **University C** | private | Master's L<br>Master's University<br>(large program) | 4,900 | 800 |
| **University D** | private, liberal arts | Master's M<br>Master's University<br>(medium program) | 2,200 | 100 |
| **University E** | private, HBCU | Bac/Diverse<br>Baccalaureate College—<br>Diverse Fields | 3,100 | 500 |

*Note: Population numbers were rounded to the nearest 100.*

For each institution, the course choices undergraduate students have the autonomy to make themselves while earning engineering degrees in various disciplines were compared to those of students earning degrees in physics, chemistry, math, economics and psychology at the same

institution. Inclusion of these degrees was informed by the University of Colorado Boulder (CU 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.

The "Choice Value" term was developed as a quantified representation of the aggregate curricular choice opportunity within a given degree program, and is a function of total course choice opportunities, the proportion of degree credit hours that provide curricular choice, and the number of courses from which students may choose. Choice Values were determined using the published curriculum in the 2013-2014 university catalogs, as well as counts for the number of individual course options for each choice opportunity.

Examples of choice opportunities within engineering degree programs include menus of course options, technical electives, humanities and social science electives, and free electives. Choice Values were calculated for each course choice opportunity in a degree program using the following equation:

*Equation 1:*

$$\boldsymbol{Choice\ Value} = \frac{(\boldsymbol{X}\text{: \# } course\ choice\ credit\ hours)}{(\boldsymbol{Y}\text{: } total\ degree\ credit\ hours)} \times (\boldsymbol{Z}\text{: \# } courses\ to\ choose\ from)$$

For example, in the case of an opportunity for a student working towards a 128-credit-hour undergraduate engineering degree to choose a 3-credit-hour "free elective" from 1,292 possible courses:

$$\boldsymbol{Choice\ Value} = \frac{3}{128} \times 1{,}292 = 30.3$$

In this example, the 1,292 courses from which the student may choose his or her free elective credit hours is based on the 2013-2014 university catalog count of all undergraduate courses of all credit hours, regardless of pre-requisites—excluding labs, independent studies, graduate courses and courses restricted to majors-only or restricted to a program, but including courses restricted to "engineering majors." The same course-counting methods were used throughout the study.

For each degree program studied, Choice Values were calculated for each curricular choice opportunity offered to students within that degree program. Choice Values for unique course choice opportunities in a given degree program were summed to arrive at a total Choice Value for the degree program. Total degree program Choice Values were normalized to 120 credit hours, a common degree credit hour requirement for the non-engineering degree programs included in the study.

## Results

Total Choice Values for all degree programs across the five universities are detailed in Table 2 and the box-and-whisker plot in Figure 1. At four universities, all engineering degree programs had lower Choice Values than all non-engineering degree programs. At University B, however, the engineering physics degree program had a Choice Value just above the physics and applied mathematics and statistics degree program Choice Values.

**Table 2:** Total choice values by degree program at five diverse institutions.

| **Engineering Degree Program (all B.S.)** | **Choice Values** | | | | |
|---|---|---|---|---|---|
| | **CU Boulder** *RU/VH*[#] | **Univ. B** *RU/H* | **Univ. C** *Mast. L* | **Univ. D** *Mast. M* | **Univ. E** *Bacc/Div* |
| Aerospace Engineering Sciences | 185.8 | | | | 8.5 |
| Architectural Engineering | 125.2 | | | | |
| Chemical Engineering | 162.5 | 52.8 | | | 8.6 |
| Chemical & Biological Engineering | 161.6 | 46.0 | | | |
| Civil Engineering | 190.9 | | 3.8 | | |
| Computer Engineering | | | 3.2 | | |
| Electrical Engineering | 171.8 | | 4.0 | | 8.0 |
| Electrical & Computer Engineering | 171.7 | | | | |
| Engineering, Mechanical Specialty | | 44.1 | | | |
| Engineering Physics | 277.1[^] | 70.8 | | | |
| Engineering Sciences | | | | 117.8 | |
| Environmental Engineering | 128.4 | | | | |
| Geological Engineering | | 45.4 | | | |
| Geophysical Engineering | | 48.5 | | | |
| Mechanical Engineering | 103.7 | | 3.1 | | 7.7 |
| Metallurg. and Materials Engineering | | 45.1 | | | |
| Mining Engineering | | 42.8 | | | |
| Petroleum Engineering | | 43.0 | | | |
| General Engineering Plus (GE+) | 405.3[^] | | | | |
| **Non-Engineering Degree Programs (B.A., unless noted)** | **CU Boulder** *RU/VH*[#] | **Univ. B** *RU/H* | **Univ. C** *Mast. L* | **Univ. D** *Mast. M* | **Univ. E** *Bacc/Div* |
| Applied Mathematics and Statistics | | 68.9* | | | |
| Chemistry | 679.6 | 91.8 | 209.6* | 315.5* | 30.8* |
| Economics | 895.6 | 118.9 | 325.1* | 534.6 | 11.0* |
| Mathematics | 828.7 | | 415.8* | 293.6 | 112.3 |
| Physics | 475.7 | 70.4 | 310.6* | 355.7* | 87.7* |
| Psychology | 1058.9 | | 419.1 | 455.0 | 89.4 |

* Denotes degree program is a bachelor of science. [^] Indicates degree program is not ABET-accredited.
[#] Acronyms for Carnegie Classifications.[11] See Table 1 for full text.

Within each of the five universities studied, an engineering degree program had the lowest Choice Value, while a non-engineering degree program had the highest Choice Value. Mechanical engineering degree programs were offered at three of the five institutions (CU Boulder, Universities C and E), and in each case represented the lowest Choice Value of the studied degree programs in each school. University D offers only one engineering degree program, engineering sciences, which had the lowest Choice Value of the degrees studied at that institution. Within Universities B and D, the economics degree programs had the highest Choice Values. At University E, the mathematics degree program had the highest Choice Value.

Within CU Boulder and University C, the psychology degree programs had the highest Choice Values. Because CU Boulder and University C also had mechanical engineering degree programs, both with the lowest Choice Values within each institution, they provide an interesting comparison of the maximum versus minimum Choice Values at two schools. CU Boulder's psychology degree program Choice Value was 10.2 times greater than CU Boulder's mechanical engineering degree program Choice Value. University C's psychology degree program Choice Value was 135.2 times greater than University C's mechanical engineering degree program Choice Value.

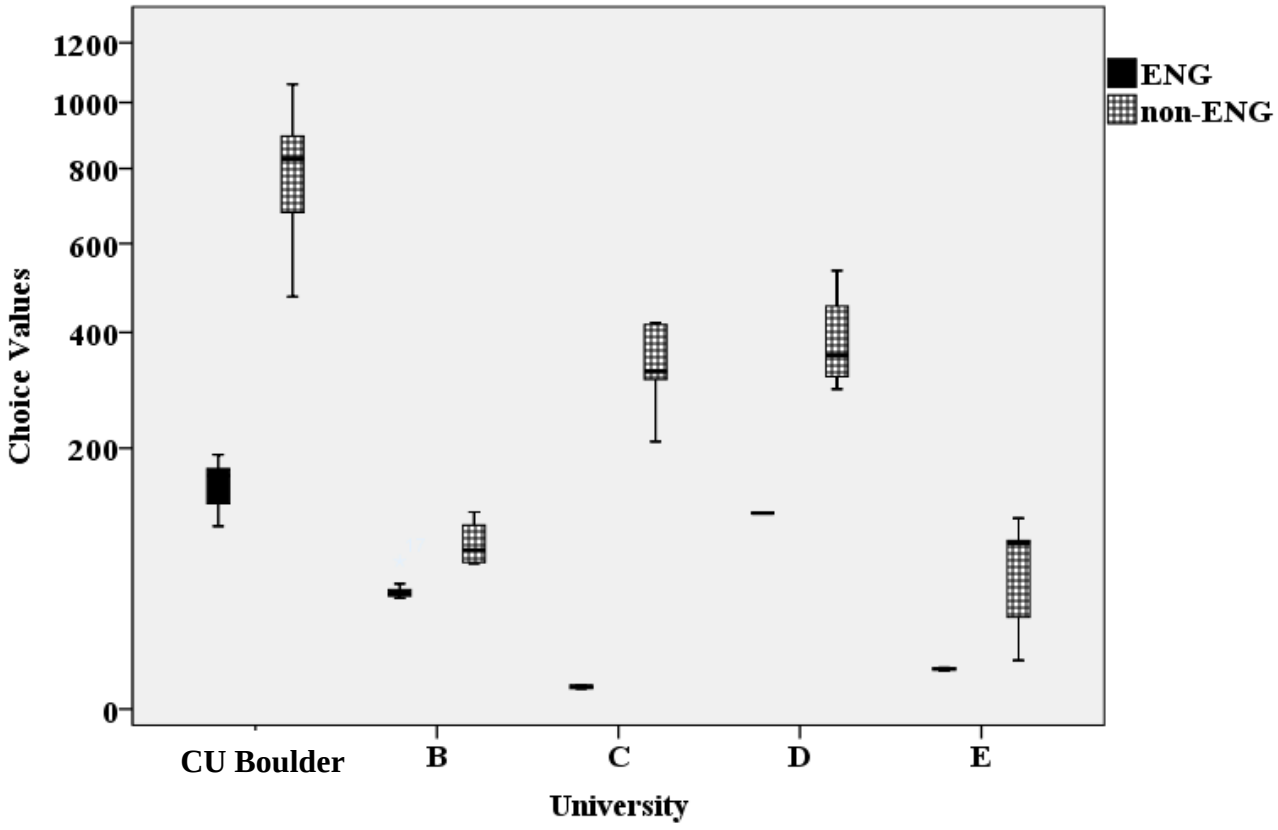


**Figure 1.** Choice values for ABET-accredited engineering degree programs vs. non-engineering degree programs at five diverse institutions.

The maximum percentage of total degree program credit hours allocated to "free electives" was also calculated for each degree program (see Table 3 and Figure 2). Free electives represent

course choice opportunities with no restrictions—students are free to choose any course and have the credit hours apply to their degrees' total credit hour requirements. While all forms of course choice opportunities were included in the Choice Value calculations (including free electives), taking an isolated look at the maximum free elective percentages provides an understanding of degree program curricular choice opportunity from a second angle.

**Table 3.** Maximum percentage of total degree program credit hours allocated to free electives, by degree program, at five diverse institutions.

| **Engineering Degree Programs (all B.S.)** | **% Degree program credit hours that are free electives** | | | | |
|---|---|---|---|---|---|
| | **CU Boulder** *RU/VH*[#] | **Univ. B** *RU/H* | **Univ. C** *Mast. L* | **Univ. D** *Mast. M* | **Univ. E** *Bacc/Div* |
| Aerospace Engineering Sciences | 3.9 | | | | 0.0 |
| Architectural Engineering | 2.3 | | | | |
| Chemical Engineering | 3.1 | 7.43 | | | 0.0 |
| Chemical & Biological Engineering | 3.1 | 6.7 | | | |
| Civil Engineering | 4.7 | | 0.0 | | |
| Computer Engineering | | | 0.0 | | |
| Electrical Engineering | 4.7 | | 0.0 | | 0.0 |
| Electrical & Computer Engineering | 4.7 | | | | |
| Engineering, Mechanical Specialty | | 6.41 | | | |
| Engineering Physics | 8.6[^] | 9.2 | | | |
| Engineering Sciences | | | | 7.0 | |
| Environmental Engineering | 2.3 | | | | |
| Geological Engineering | | 6.59 | | | |
| Geophysical Engineering | | 6.79 | | | |
| Mechanical Engineering | 1.6 | | 0.0 | | 0.0 |
| Metallurg. and Materials Engineering | | 6.50 | | | |
| Mining Engineering | | 6.45 | | | |
| Petroleum Engineering | | 6.45 | | | |
| General Engineering Plus (GE+) | 14.8[^] | | | | |
| **Non-Engineering Degree Programs (B.A., unless noted)** | **CU Boulder** *RU/VH*[#] | **Univ. B** *RU/H* | **Univ. C** *Mast. L* | **Univ. D** *Mast. M* | **Univ. E** *Bacc/Div* |
| Applied Mathematics and Statistics | | 10.0* | | | |
| Chemistry | 26.7 | 6.7 | 13.3* | 22.6* | 2.5* |
| Economics | 35.0 | 16.4 | 21.1* | 39.5 | 0.0* |
| Mathematics | 32.5 | | 27.3* | 20.2 | 12.9 |
| Physics | 18.3 | 9.2 | 20.3* | 25.8* | 0.0* |
| Psychology | 41.7 | | 27.3 | 33.1 | 12.2 |

* Denotes degree program is a bachelor of science.

[^] Indicates degree program is not yet ABET-accredited. GE+ plans to seek ABET-accreditation after the first students graduate from the program in 2017.

[#] Acronyms for Carnegie Classifications.[11] See Table 1 for full text.

Within each of the five universities studied, the lowest percentage free elective offering was seen in an engineering degree program, while the highest percentage free elective offering was seen in a non-engineering degree program. Within CU Boulder, University C, and University D, all engineering degree programs allocated fewer credit hours to free electives than all non-engineering degree programs. At Universities C and E, no engineering degree programs offered any free elective choice opportunities to students.

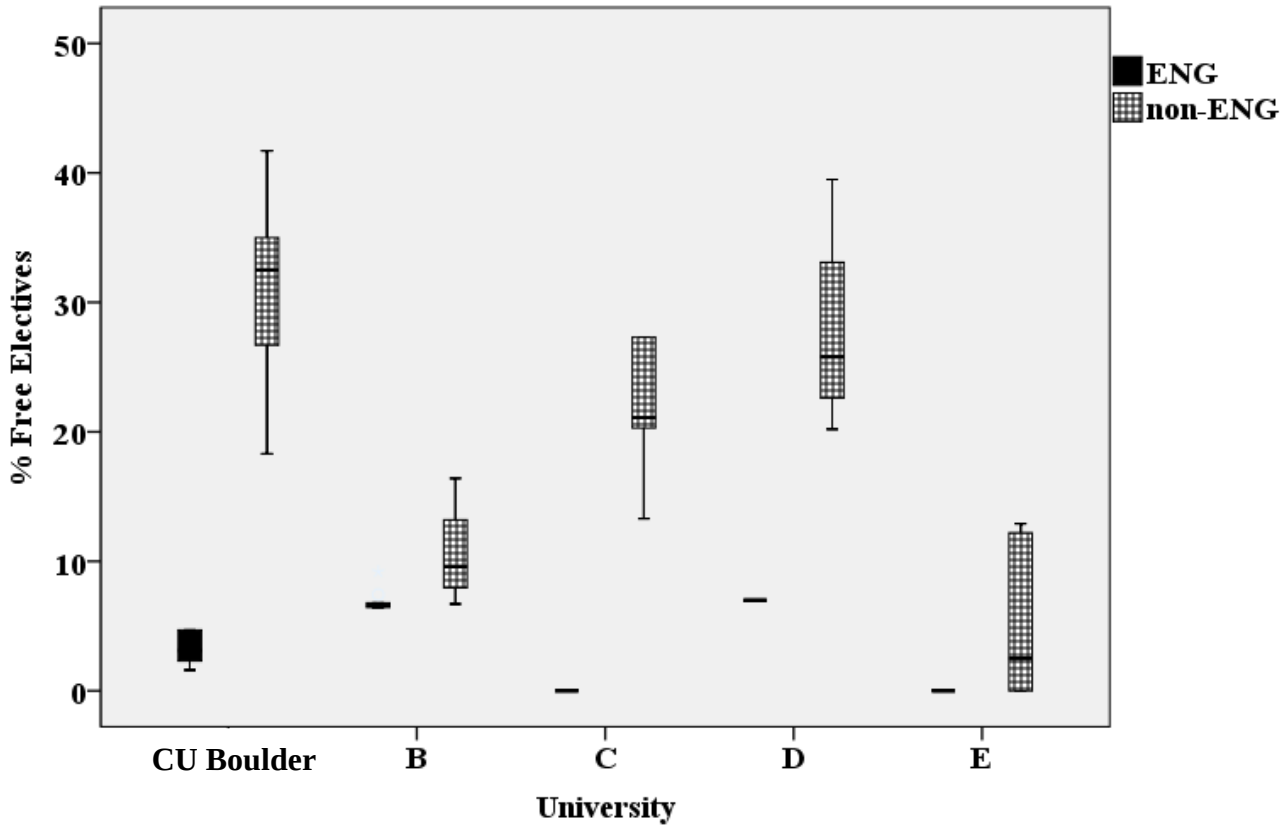


**Figure 2.** Maximum percentage of total degree program credit hours allocated to free electives, for ABET-accredited engineering degree programs vs. non-engineering degree programs at five diverse institutions.

*University of Colorado Boulder*

CU Boulder is a large, public Research University (very high research activity)[11] with a 2013 undergraduate university population of approximately 26,000 students and a full-time undergraduate engineering population of approximately 3,700 students.

Engineering degree program Choice Values for CU Boulder were an average of 4.7 times lower than Choice Values for physics, chemistry, mathematics, economics and psychology degree programs within the university. This average value was calculated by dividing each engineering degree program Choice Value for CU Boulder by each CU Boulder Choice Value for physics, chemistry, mathematics, economics and psychology, respectively, and taking the average across all such values to arrive at 4.7.

Engineering degree programs at CU Boulder had an average of only 4.9% of total degree credit hours allocated to free electives, compared to an average of 30.8% of physics, chemistry, mathematics, economics and psychology degree credit hours. Of the 11 engineering degree programs at CU Boulder, nine allotted less than 5% of total degree credit hours to free electives—compared to 18% for physics, 27% for chemistry, 33% for mathematics, 35% for economics and 41% for psychology total degree credit hours.

Compared to other engineering degree programs at CU Boulder, the new General Engineering Plus (GE+) degree program had an exceptionally high Choice Value and maximum free elective percentage; however both are still below the range of these values for the non-engineering degrees. The GE+ program is presented in the next section of this paper.

Variability of engineering degree program Choice Values within CU Boulder was 3.9 (calculated by dividing the maximum engineering degree Choice Value by the minimum engineering degree Choice Value). Excluding GE+, which inflates this value, variability across all other engineering degree programs in the CEAS was 2.7.

*University B*

University B is a public Research University (high research activity) [11] with a 2013 undergraduate university population of approximately 4,300 students and a full-time undergraduate engineering population of approximately 4,000 students.

Engineering degree program Choice Values for University B were an average of 1.8 times lower than the physics, chemistry, economics, and applied mathematics and statistics Choice Values at the institution. University B does not have a psychology degree program. Variability of engineering degree program Choice Values within University B was 1.7.

Engineering degree programs at University B had an average of 7.0% of total degree credit hours allocated to free electives, compared to an average of 10.6% of physics, chemistry, economics, and applied mathematics and statistics degree credit hours. With the exception of economics, all degree programs studied at University B allotted less than 10% of total degree credit hours to free electives, indicating that the relatively smaller separation in Choice Values between engineering and non-engineering degree programs found at University B is less a reflection of highly self-determinant engineering degrees and more a reflection of less curricular choice across the board at this institution. This trend is perhaps not surprising considering that University B is a technically focused institution, with more than 90% of the school's undergraduate population enrolled in engineering degree programs.

*University C*

University C is a private, Master's University (large program) [11] with a 2013 undergraduate university population of approximately 4,900 students and a full-time undergraduate engineering population of approximately 800 students.

Engineering degree program Choice Values for University C were an average of 96.1 times lower than University C's physics, chemistry, mathematics, economics and psychology degree

program Choice Values. Variability of engineering degree program Choice Values within University C was 1.3.

None of the engineering degree programs at University C provide any free electives choice opportunities to their students, compared to an average free elective allocation of 21.9% for their physics, chemistry, mathematics, economics and psychology degree programs.

*University D*

University D is a private, liberal arts Master's University (medium program) [11] with a 2013 undergraduate university population of approximately 2,200 students and a full-time undergraduate engineering population of approximately 100 students.

The Choice Value for University D's engineering degree program was an average of 3.3 times lower than their physics, chemistry, mathematics, economics and psychology degree programs.

University D's engineering degree program consisted of 7.0% free electives, compared to their average of 28.2% for physics, chemistry, mathematics, economics and psychology degree program credit hours.

*University E*

University E is a private, HBCU, Baccalaureate College—Diverse Fields[11] with a 2013 undergraduate university population of approximately 3,100 students and a full-time undergraduate engineering population of approximately 500 students.

Choice Values for the engineering degree programs at University E were an average of 8.1 times lower than their physics, chemistry, mathematics, economics and psychology degree program Choice Values. Variability of engineering degree program Choice Values within University E was 1.1.

None of the engineering degree programs at University E provided any free electives choice opportunities to students, which was also true for their physics and economics degree programs. Other free elective percentages at the institution were: 12.9% for mathematics, 2.5% for chemistry and 12.2% for psychology degree programs.

*Summary of Results across the Five Universities Studied*

Within institutions, the amount of curricular choice available to engineering students was rather consistent; the variability in Choice Values between different engineering majors was typically within a factor of 2. However, Choice Values for mechanical engineering degrees varied by a factor of 33 between CU Boulder and University C, while Choice Values for civil engineering degrees varied by a factor of 51 across the same institutions—indicating that choice within engineering degrees can vary significantly between institutions. In this example, the civil engineering degree at CU Boulder provided students with 13 more credit hours of choice than the mechanical engineering degree (four more free electives, six more non-engineering technical electives, and three more engineering electives), while at University C the civil and mechanical engineering degree course choices were nearly identical (with the exception of three extra

technical elective credit hours allocated to the civil engineering students). Further discussion on Choice Value comparisons across institutions is presented in the "Study Limitations" section below.

Across the five universities and degree programs studied, engineering degree program Choice Values were an average of 17.9 times fewer than the Choice Values for the non-engineering degree programs, with a median value of 4.7 and a range of 1.8 to 96.1 times lower Choice Values for engineering. Engineering degree programs allocated an average of 4.3% of total degree credit hours to free electives, compared to 19.8% of total degree credit hours for non-engineering degree programs included in the study. Thus, for a normalized 120-credit program, engineering students at these schools choose an average of five credit hours as free electives, whereas their across-campus peers in the studied degree programs choose an average of 24 free elective credit hours. Thinking about these numbers from a student point-of-view, if we visualize students using only one 3-credit-hour free elective at a time throughout a four-year degree, this would mean that *three years* go by without the engineering students picking any free electives, while their non-engineering peers choose a free elective every semester.

**Approaching Choice Opportunity Parity: *The General Engineering Plus Degree Program***

Certainly, not all engineering students are thrilled with the comparatively small amount of curricular choice they are afforded. In November 2012, 24% of the University of Colorado Boulder undergraduate engineering student population (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=570) and 53% of female (n=121) respondents.

In 2013, CU Boulder inaugurated the General Engineering Plus (GE+) degree program, "a customizable design-based degree comprised of core engineering and design courses, a disciplinary emphasis and a pre-approved concentration"[10] of the students' choice. The first student cohort matriculated into the GE+ degree program in fall 2014, with 25 first-year students and 19 sophomore through senior transfer students.

Students in the GE+ program complete four or more project-centered design courses, five required core engineering courses, choose a 15-credit-hour engineering discipline emphasis (aerospace, architectural, civil, electrical, environmental or mechanical), and 12 or more credit hours in a technical or non-technical "concentration" of their own choosing. Concentrations must be pre-approved, purposeful sequences of courses, generally culminating in at least one senior-level course. Concentration examples include engineering management, entrepreneurship, environmental policy, business, pre-med, and Spanish culture & language. Teach Engineering is also offered as a concentration, providing a unique teacher preparation pathway through engineering that results in secondary teacher licensure preparation in math or science.

The coupling of the design-focused engineering degree with a specialized concentration aims to provide students with a "flexible, yet technical, career path,"[10] with "concentrations support[ing] subsequent pursuit of graduate or professional programs in areas such as medical or law school,

or professional practice in generalized engineering areas such as technical sales or project management,"[10] as well as careers in secondary science or math teaching.

The GE+ degree requires completion of the same 128-credit-hour total as all other engineering degrees in the CEAS, has the same mathematics, science and humanities requirements, as well as the same academic standards as the rest of the college. Like other engineering degree programs in the college, the GE+ program will seek ABET accreditation after the first students have graduated. Thus, the GE+ program consists of parallel requirements, framework, and academic expectations, but is differentiated from its engineering degree counterparts within the institution by its amount of curricular choice.

The GE+ Choice Value is 405.3 (see Table 2), an average of only 1.9 lower than the Choice Values for the physics, chemistry, mathematics, economics, and psychology degree programs on campus. Excluding GE+, all other engineering degree program Choice Values for the institution (CU Boulder) were an average of 5.0 times lower than Choice Values for physics, chemistry, mathematics, economics and psychology degree programs at CU Boulder.

And, the GE+ Choice Value is an average of 2.6 times greater than Choice Values of all other engineering degree programs at CU Boulder. GE+ students get a maximum of 14.8% of their total degree credit hours (19 credits) allocated to free electives, compared to other engineering students on campus who may explore with only 3.9% (five credits) of their degrees as free electives.

The data presented in this study demonstrate GE+'s unique offering for engineering students to explore and experience curricular choice at a level previously unseen in the CEAS—a level *almost* approaching parity to the most restrictive non-engineering degree programs included in this study at the University of Colorado Boulder. We hypothesize that this might make a difference for who comes—and stays—in the engineering college, perhaps providing insight into a yet-undiscovered pathway to broaden participation in engineering.

**Study Limitations**

Choice is not a mathematical construct, and any attempt to quantify it is inevitably flawed—including the notion of Choice Values included in this study. The information contained in a Choice Value is limited, and simply presents a one-dimensional view of the self-determination opportunity provided by a given course choice.

Numerous sources of error are unavoidably present in the course count method used to arrive at Choice Values (see value "**Z**" in Equation 1), including the issue of prerequisites, human error certain to occur in such extensive counting, the limitations of student schedules, and that not all courses are offered every year. Additionally, some courses may be listed in more than one department, causing them to be counted more than once, while others may also be a requirement of the major, and therefore would not be chosen by a student for a given course choice opportunity. Nonetheless, this direct-counting Choice Value method provides a useful means of understanding the scale of course choice opportunities within a given degree program, revealing how much self-determination freedom is provided by a given choice opportunity. Thus, these values allow for meaningful comparison from program to program within an institution.

Because smaller schools predictably offer fewer courses overall, they are at risk to be disadvantaged by lower Choice Values (again, see value "**Z**" in Equation 1). Taking the example of free elective course choice opportunities for engineering students across the five universities, at CU Boulder those students get to choose their free electives from 2,508 courses, while the engineering students at University E choose their free electives from 674 courses. This makes sense considering the undergraduate population at CU Boulder is over eight times the population at University E, so naturally CU Boulder offers far more courses than University E. The engineering students' free elective "**Z**" values at universities B, C, and D are 700, 1528, and 1292, respectively. Though free electives represented the largest range of "**Z**" values between institutions, "**Z**" value variations of smaller scale were encountered between institutions for other course choice opportunities (such as humanities electives and technical electives) simply due to the varying amount of courses offered at these schools with a range of undergraduate populations. As such, Choice Value comparisons between institutions can only responsibly be done from *within* multiple degree programs *across* the same universities, for example comparing from *within* mechanical engineering *across* CU Boulder and University C to *within* electrical engineering again *across* CU Boulder and University C.

With the inclusion of only five universities in this preliminary study, this work must be expanded to a larger sample size. Future work will grow the study of choice opportunity disparity between engineering and non-engineering majors to the 40 top-ranked engineering colleges in the U.S. In this future work, the Choice Value metric will evolve into multiple variables, each designed to capture different dimensions of choice within a curricular choice opportunity.

**Discussion**

Educational environments that support autonomy have been shown to foster self-motivation, increased engagement, higher-quality learning and personal well-being.[4,5,6] The limited course choice opportunities that engineering students encounter reflects the notoriously restrictive and lock-step nature of many engineering degree programs, and may be a contributor to the field's numerous, persistent access and retention challenges.

Across the board at the five diverse schools included in this study, engineering students have exceptionally little autonomy in choosing their courses compared to their non-engineering peers. The psychological effects of the comparatively lower Choice Values and fewer free elective choice opportunities experienced by these undergraduate engineering students are unknown. This *choice opportunity disparity* leads to the question of how undergraduate engineering degree programs might improve their course choice opportunities, and if doing so could positively impact broadening participation in engineering enrollments and improve graduation rates.

Students with broader non-technical interests in engineering degree programs often get filtered out, [8] receiving neither the encouragement nor opportunity to explore non-technical academic interests. Students in the University of Colorado Boulder's CEAS with interests that extend beyond the core engineering degree (either technical or non-technical) can now pursue those interests *without leaving engineering*. Engineering students looking to satisfy their developmental and psychological needs to explore and choose their own courses now have a place to go—in engineering—where they can experience meaningful self-determination opportunities within an engineering education setting. How will the presence of this degree

program in the CEAS impact educational outcomes college-wide? How will GE+'s increased curricular choice opportunity affect the pathways of students "to" and "through" undergraduate engineering? The General Engineering Plus degree program is still in its infancy, with the graduation of the first cohort of students a few years away; so in this case, time will tell.

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