

## **Exploring Impacts of Flexible, Balanced Engineering Program Curricula**

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# Exploring Impacts of Flexible, Balanced Engineering Program Curricula

## Abstract

Having choices is linked to both human satisfaction and motivation. A quantitative exploration of curricular choice opportunities across dozens of undergraduate engineering programs yielded evidence of a low-choice culture in engineering education, with engineering students commonly afforded minimal curricular choice and few opportunities to pursue a broad, balanced education compared to their campus peers. Exceptional, highly regarded and accredited engineering programs, while few in number, demonstrated the feasibility of highly flexible, customizable, and balanced programs. Though hypothesized that the low-choice, highly technical engineering curricular model may be a barrier to participation in engineering education, correlations between curricular choice/balance and educational outcomes had not been explored. In this pilot study, curricula and program outcome data were delineated for 21 engineering, math, natural science, and physical science degree programs (nine ABET-accredited, 12 non-accredited) at the University of Colorado Boulder to probe correlations between the amount of course choice and technical—non-technical curricular balance provided by a given program and the program's 1) median time to degree, 2) six-year graduation rate, 3) average GPA, and 4) percentage of bachelor's degrees earned by women. Results were mixed as to the potential benefits of flexible, balanced engineering programs, and numerous confounding factors were present in the study. Cross-institutional research that mitigates confounding factors is needed to further explore correlations between engineering program curricular choice opportunities, balance and educational outcomes.

## Introduction

Autonomy, satisfied through choice, is a fundamental human need.<sup>1,2</sup> Promoting a sense of choice has been linked to motivation, well-being, creativity, cognitive flexibility, and self-esteem.<sup>1</sup> Specific to education, providing choices in classroom settings has been linked to increased engagement and higher-quality learning.<sup>1,2</sup> It is unknown whether and how choice opportunities impact students at a more macro level in course selection.

In previous studies, the authors questioned engineering students' ability to satisfy their need for choice as they commonly navigated through undergraduate programs that were overly constrained as compared to non-engineering programs.<sup>3,4,5,6,7,8</sup> One study across dozens of universities revealed that free electives (course selections with no restrictions) comprised a median of just 3% of engineering programs versus 24% for non-engineering programs on the same campuses. And, engineering students could choose a median of 40% of their degree courses versus 74% for the non-engineering students.<sup>4</sup>

The overly constrained engineering programs were also often very technically focused. Despite that the ABET Engineering Accreditation Commission (EAC) requires a minimum of 63% technical coursework, engineering students across more than 100 programs were generally more constrained in their ability to realize a broad and balanced education, and were required to take a median of 78% technical coursework (engineering, math and natural science).<sup>4</sup> However, exceptional, highly regarded engineering programs were identified that facilitated a flexible,

broad and reputable engineering education that was balanced with substantial opportunity for student integration of non-technical coursework.<sup>3,4,5,6</sup>

The findings of a mainstream, exceedingly constrained undergraduate engineering culture seems not only potentially at odds with the autonomy-supportive needs of students, but also a logistical barrier for students entering into and matriculating through programs, and a possible contributor to the low rate of in-migration to engineering.<sup>9</sup> The fewer free electives in a program, the less opportunity for students to transfer in and have their existing credits “count” towards graduation, which is increasingly important (especially to broaden participation) as the cost to attend college continues to rise steeply.<sup>10</sup>

A focus exists in education research and engineering education research to identify correlation factors to college graduation and changes/interventions designed to support success. A comprehensive 2011 study found that college degree attainment rates varied by student group and educational setting: women attain degrees at higher rates than men; first-generation students lower than non-first-generation students; Asian students have the highest degree attainment rates; underrepresented minority students attain degrees at lower rates than white students; and private universities have higher graduation rates than public universities. Among other factors, high school GPA and SAT composite scores correlated to college graduation rates.<sup>11</sup>

Specific to engineering education, a study that evaluated current engineering college admission practices in relation to college graduation predictors found that standardized test scores had limited predictive power while high school GPA was a better predictor of engineering college graduation.<sup>12</sup> The study, which employed datasets that included more than a million students, concluded that, “diversity in engineering can be expanded, with data-supported confidence in engineering graduation rates, if engineering colleges aggressively admit more next-tier students who boast top high school performance—within the top quartile of high school grade point average of admitted students—yet have much lower standardized test scores (SAT or ACT) than are typical at the institution.”<sup>12</sup>

In the present pilot study, the authors move past the investigation of choice and balance in undergraduate engineering to explore whether curricular customizability and balance are also factors linked to student success that might have similarly actionable implications. *Are tangible educational benefits, such as broadened participation and improved academic performance and graduation rates, correlated to increased course choice opportunity and/or curricular balance in undergraduate engineering degree programs?*

## **Methods**

University of Colorado Boulder curricula and program outcome data were delineated for 21 bachelor’s degree programs (nine of art, 11 of science, one of environmental design), including all current College of Engineering and Applied Sciences (CEAS) (12), natural sciences (7), and physical sciences (2) majors that were started before the 2000-2001 academic year (Table 1). The environmental design degree was housed in the College of Architecture and Planning. Eight of the programs were accredited by ABET’s EAC; one was Computing Association Commission (CAC)-accredited; 12 were non-accredited.

The admissions criteria for majors in the CEAS differed from those in the College of Arts and Sciences. These differences were reflected in the average high school GPA of the first-year

students who matriculated into various majors, which ranged from a high of 3.90 in Aerospace Engineering to a low of 3.28 in Geography (based on the fall 2008 class).

**Table 1.** The 21 studied undergraduate degree programs.

<b>Degree Program</b>	<b>Degree Type</b>	<b>ABET</b>	<b>Category</b>	<b>Total Req'd Degree Credits</b>	<b>Bach. Degrees Awarded<sup>1</sup> (n)</b>	<b>6-Year Grad. Rate<sup>2,3</sup> (%)</b>	<b>% Bach. Degrees to Women<sup>3</sup></b>	<b>Avg High School GPA<sup>4</sup></b>
Aerospace Engineering Sciences	BS	EAC	CEAS	128	220	39	22	3.90
Applied Mathematics	BS	None	CEAS	128	94	53	25	3.89
Architectural Engineering	BS	EAC	CEAS	128	122	54	23	3.80
Chemical Engineering	BS	EAC	CEAS	128	139	49	36	3.83
Civil Engineering	BS	EAC	CEAS	128	170	48	18	3.78
Computer Science	BS	CAC	CEAS	128	189	36	13	3.74
Elec. and Computer Engineering	BS	EAC	CEAS	128	104	25	8	3.77
Electrical Engineering	BS	EAC	CEAS	128	121	41	6	3.85
Engineering Physics	BS	None	CEAS	128	49	38	21	3.80
Environmental Engineering	BS	EAC	CEAS	128	68	36	50	3.79
Mechanical Engineering	BS	EAC	CEAS	128	408	52	14	3.82
Environmental Design	BEnvd	None	Arch. and Planning	128	537	54	42	3.62
Ecology and Evolutionary Biology	BA	None	Natural Science	120	423	35	56	3.65
Environmental Studies	BA	None	Natural Science	120	451	35	41	3.51
Geography	BA	None	Natural Science	120	222	39	36	3.28
Geological Sciences	BA	None	Natural Science	120	102	35	29	3.56
Integrative Physiology	BA	None	Natural Science	120	800	42	63	3.72
Molecular, Cellular and Dev. Biology	BA	None	Natural Science	120	456	35	55	3.71
Psychology	BA	None	Natural Science	120	1609	48	72	3.51
Chemistry and Biochemistry	BA	None	Physical Science	120	297	25	40	3.61
Physics	BA	None	Physical Science	120	99	29	19	3.61

<sup>1</sup>Frequency count of all bachelor's degrees awarded by major for the 2000-2001, 2004-2005, and 2008-2009 AYs.

<sup>2</sup> For students from the entering first-year cohort who started in the major and ended in the major.

<sup>3</sup>Averaged across the 2000-2001, 2004-2005, and 2008-2009 academic years.

<sup>4</sup>For first-year students matriculated into major in fall 2008.

For each degree program, curricular choice and balance data (outlined below) was gathered from the 2000-2001, 2004-2005, and 2008-2009 course catalogues, respectively. For each metric, the 2000-2001 and 2004-2005 data values were averaged and paired (respectively) with four similarly averaged educational outcome metrics from the original entering year cohort upon graduation: 1) median time to degree, 2) six-year graduation rate, 3) average college GPA upon graduation, and 4) percentage of bachelor's degrees earned by women. The method of averaging and pairing provided a smoothing effect from misleading fluctuations that could result from smaller sample sizes for a given degree program. For each of the studied years, the degree programs awarded a median of 63 bachelor's degrees (ranging from 14 to 559). Curriculum metrics and educational outcome metrics were likewise averaged and paired with one another for the 2004-2005 and 2008-2009 entering cohorts, thus providing two paired curriculum and educational outcome data points (a total of 42) for each of the 21 degree programs of interest.

Six-year graduation rates were used as a success metric for this study because “many students today take five years to complete baccalaureate degrees... the likelihood that a student will eventually complete a degree quickly decreases after five years”; and reporting six-year graduation rates is more fair across student groups and institution types.<sup>11</sup> Based on the divergent admission criteria between the CEAS and CAS students (with higher average high school GPAs for the CEAS majors) and the previously referenced correlation between high school GPA and likelihood of graduation, higher six-year graduation rates were expected for the engineering students, presenting a known confounding factor (among others) that is discussed later in this paper.

#### *Curricular Choice*

Curricular choice was delineated for each degree program using data for three metrics that were gathered from the 2000-2001, 2004-2005, and 2008-2009 online university catalogs, respectively: 1) “percent free electives,” the percentage of total degree credit hours that were free electives with no restrictions placed on course selections; 2) “percent total choice,” the percentage of total degree credit hours that offered students a choice in the courses they could take, including free electives, technical electives, humanities electives, etc., or picking from a menu or list of course options; and 3) “no choice,” the total number of required credits without choice, to account for differences in total credits to degree (see Table 1).

#### *Curricular Balance*

Data for two curricular balance metrics were also gathered from the same university catalogs for each degree program: 1) the total percentage of the degree program that consisted of required technical coursework (“technical”) and 2) the percentage of required non-technical coursework (“non-technical”). Technical was defined as coursework in engineering, math, and natural science; non-technical was all coursework outside of engineering, math, and natural science.

#### *Statistical Analyses, Software, and Data Presentation*

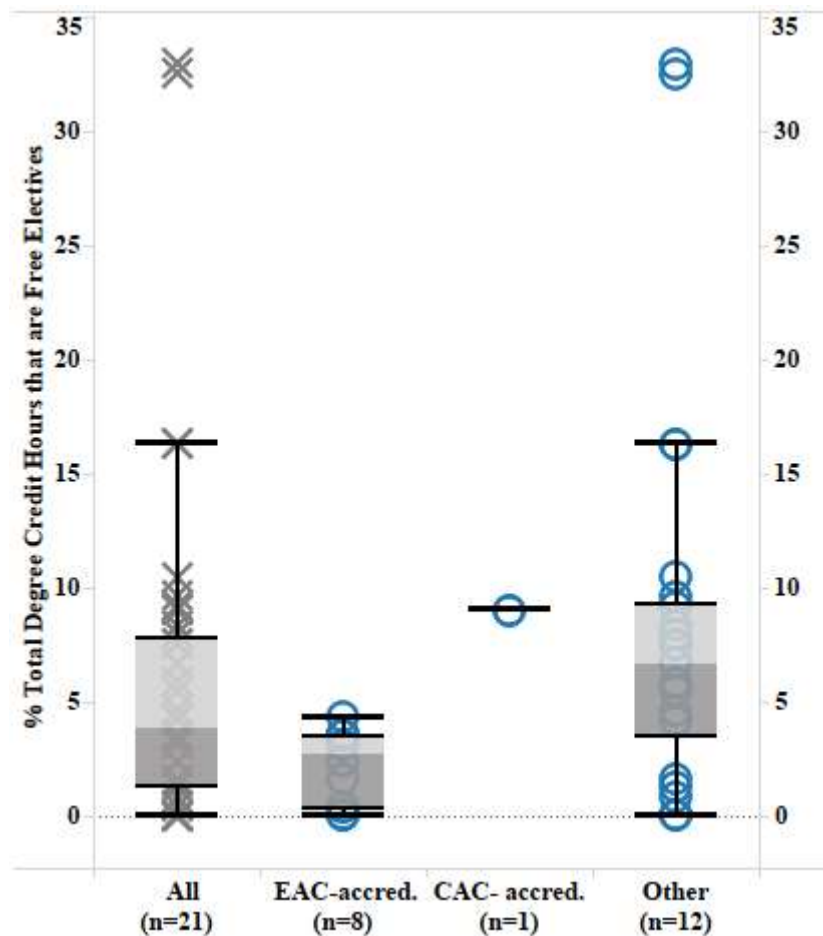
The gathered data were ordinal in nature; therefore, median (M) values are reported and non-parametric statistical analyses were employed. Mann-Whitney U tests were used to detect differences between two independent groups. The Spearman's rho correlation statistical test was used to test for coefficients of association between curricular choice/balance metrics and the educational outcome metrics. Statistical analyses were performed using MVPstats;  $\alpha = 0.05$ .

The data are presented in box-and-whisker plot format that displays the median (the center of the box), first quartile (lower extent of the box), third quartile (upper extent of the box), and maximum (upper extent of whisker) and minimum (lower extent of whisker). In some cases, statistical outliers extend beyond the whiskers.

## Results and Discussion

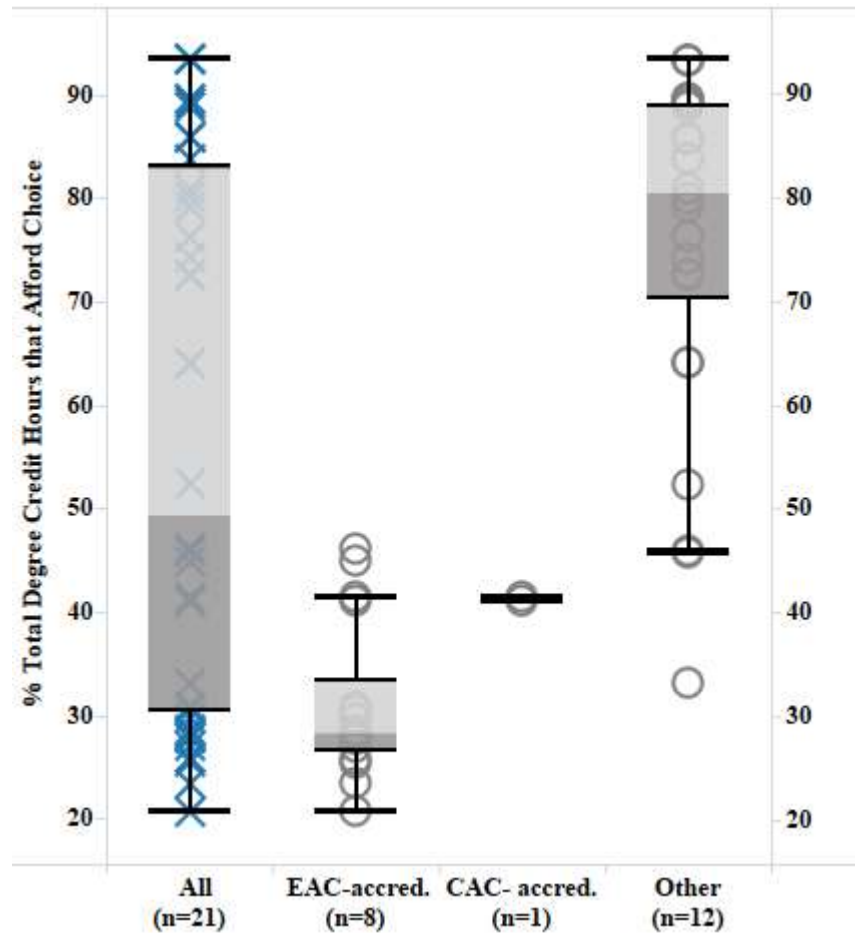
### Curricular Choice

*Free Electives.* The free elective percentages for the 21 studied undergraduate degree programs are presented in Figure 1. At the median, the programs allotted 4% free electives ( $M_{EAC}=3\%$ ,  $M_{CAC}=9\%$ ,  $M_{other}=7\%$ ); the EAC-accredited programs afforded students less free elective opportunity than the studied non-accredited programs (Mann-Whitney U  $p=0.008$ ). The BS programs allocated a median of only 2% of their total credit hours to free electives while their BA counterparts had a median of 8% free elective choice (Mann-Whitney  $p=0.000$ ).



**Figure 1.** Percent free electives for 21 undergraduate degree programs.

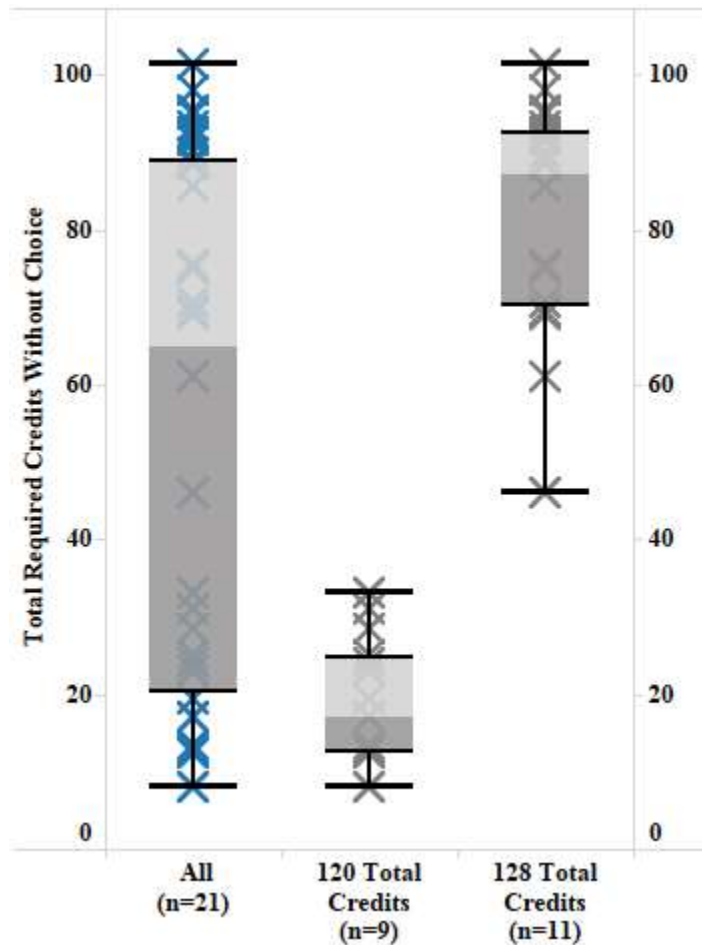
*Total Choice.* The percentages of total degree credit hours that offered students choices in the courses they could take are presented in Figure 2. The programs provided a median of 49% total choice ( $M_{EAC}=28\%$ ,  $M_{CAC}=41\%$ ,  $M_{other}=80\%$ ); the EAC-accredited programs afforded students far less total choice than the studied non-accredited programs (Mann-Whitney U  $p=0.000$ ). The median of BS programs also provided far less total choice ( $M_{BS}= 32\%$ ) than the BA programs ( $M_{BA}= 86\%$ ) (Mann-Whitney  $p=0.000$ ).



**Figure 2.** Percent total choice for 21 undergraduate degree programs.

*No Choice.* The total number of credit hours with no choice for the 21 studied programs are presented in Figure 3. The programs requiring 128 total degree credit hours (each of which was housed in the College of Engineering and Applied Science) required considerably more “no choice” credits (M=87) than the 120 credit hour programs from the College of Arts and Sciences (M=17) (Mann-Whitney U p=0.000).

The logistical difficulty of the substantial “no choice” requirements amidst a vast total credit hour requirement for engineering students is compounded by the fact that some required courses are only offered once per year and are part of long pre-requisite chains; a setback to a link in one such chain can substantially extend students’ time-to-degree (and therefore, cost).

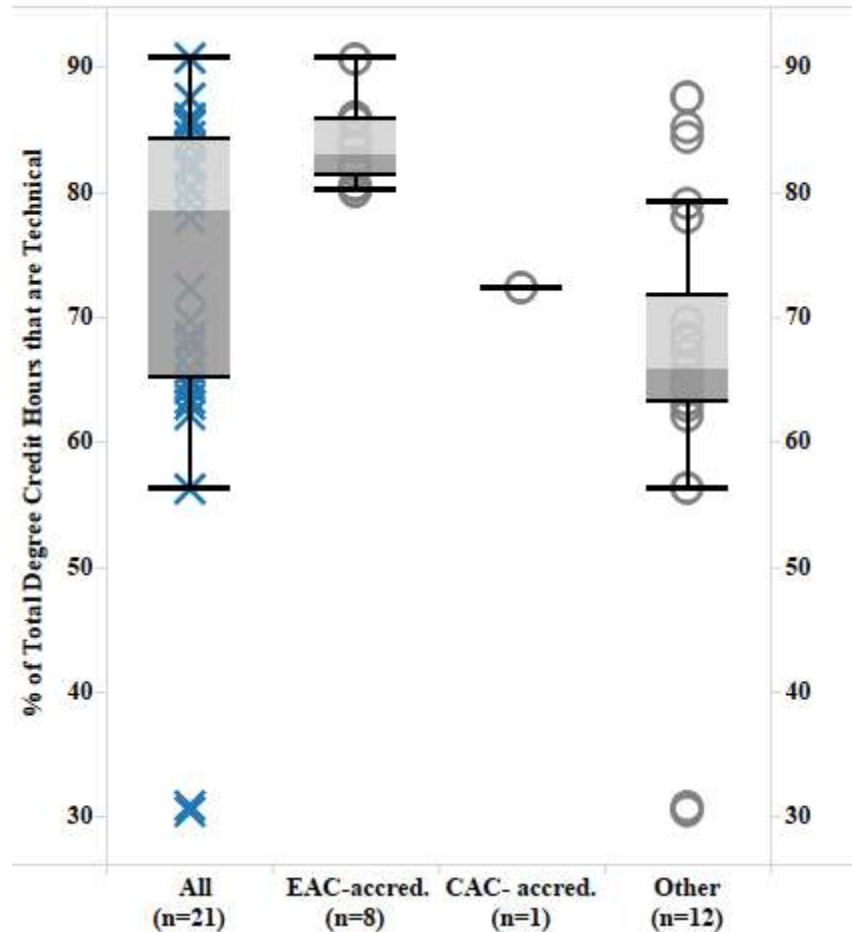


**Figure 3.** Total required credits without choice for 21 undergraduate degree programs.



### Curricular Balance

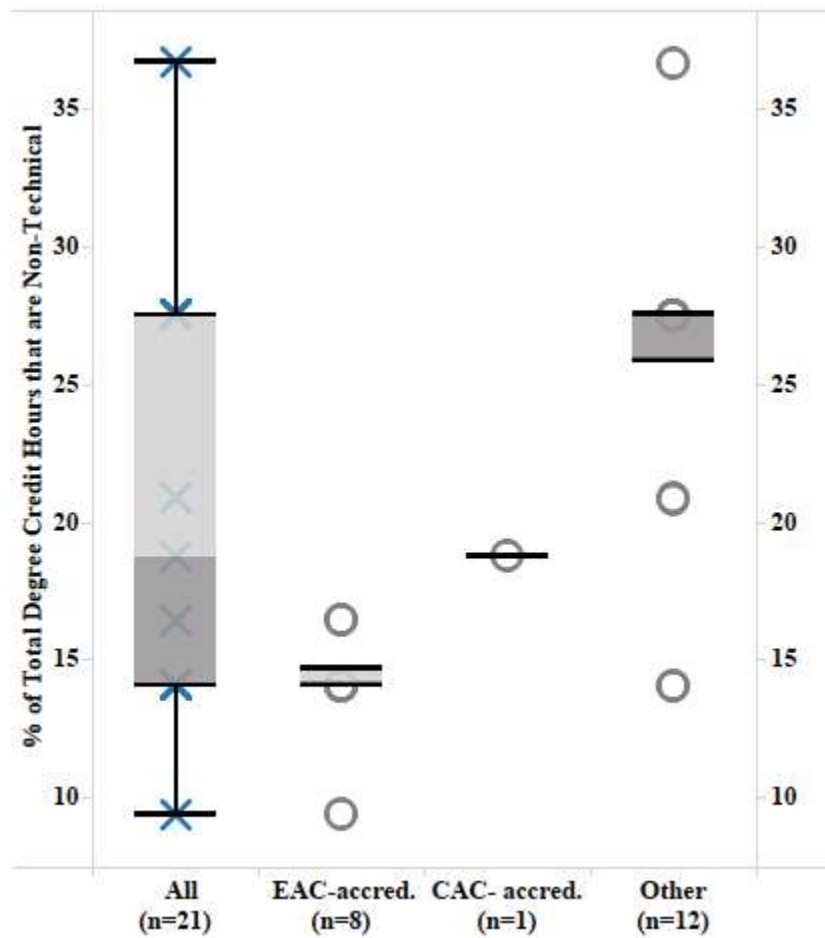
*Technical.* The percentages of required technical coursework are presented in Figure 4. The programs required students to take a median of 79% technical coursework ( $M_{EAC}=83\%$ ,  $M_{CAC}=72\%$ ,  $M_{other}=66\%$ ); the EAC-accredited programs required more technical coursework than the studied non-accredited programs (Mann-Whitney U  $p=0.002$ ). It is notable that the EAC-accredited programs required a median of 83% technical coursework, as compared to the ABET EAC minimum requirement of 63%. Not surprisingly, BS programs required noticeably more technical coursework ( $M_{BS}=83\%$ ) than the BA programs ( $M_{BA}=65\%$ ) (Mann-Whitney  $p=0.000$ ).



**Figure 4.** Percent technical credit hours for 21 undergraduate degree programs.

*Non-Technical.* The percentages of required non-technical coursework are presented in Figure 5. The 21 programs required students to take a median of 19% non-technical coursework ( $M_{EAC}=14\%$ ,  $M_{CAC}=19\%$ ,  $M_{other}=28\%$ ). The BS programs required less non-technical coursework ( $M_{BS}=14\%$ ) than the BA programs ( $M_{BA}=28\%$ ) (Mann-Whitney  $p=0.000$ ). The EAC-accredited programs required less non-technical coursework than the studied non-accredited programs (Mann-Whitney U  $p=0.000$ ). Worth noting, the College of Arts and Sciences students were required to take a “core curriculum” that included skills acquisition and covered seven content areas of study (historical context, cultural and gender diversity, United States context, literature and the arts, contemporary societies, ideals and values, and natural science) and comprised a minimum of 30 non-technical hours—from which engineering students were exempt and were instead required to take just one writing class and five other non-technical courses (18 credits total) that they could choose from hundreds of options.<sup>13</sup>

The engineering student exemption from the broader common core is notable given two things: 1) that it would be feasible to integrate the common core courses into ABET’s flexible accreditation model; and 2) virtually universal agreement exists in the literature that a strong foundation of humanities and social sciences is essential for an effective, responsible engineering education.<sup>14-30</sup>



**Figure 5.** Percent non-technical credit hours for 21 undergraduate degree programs.

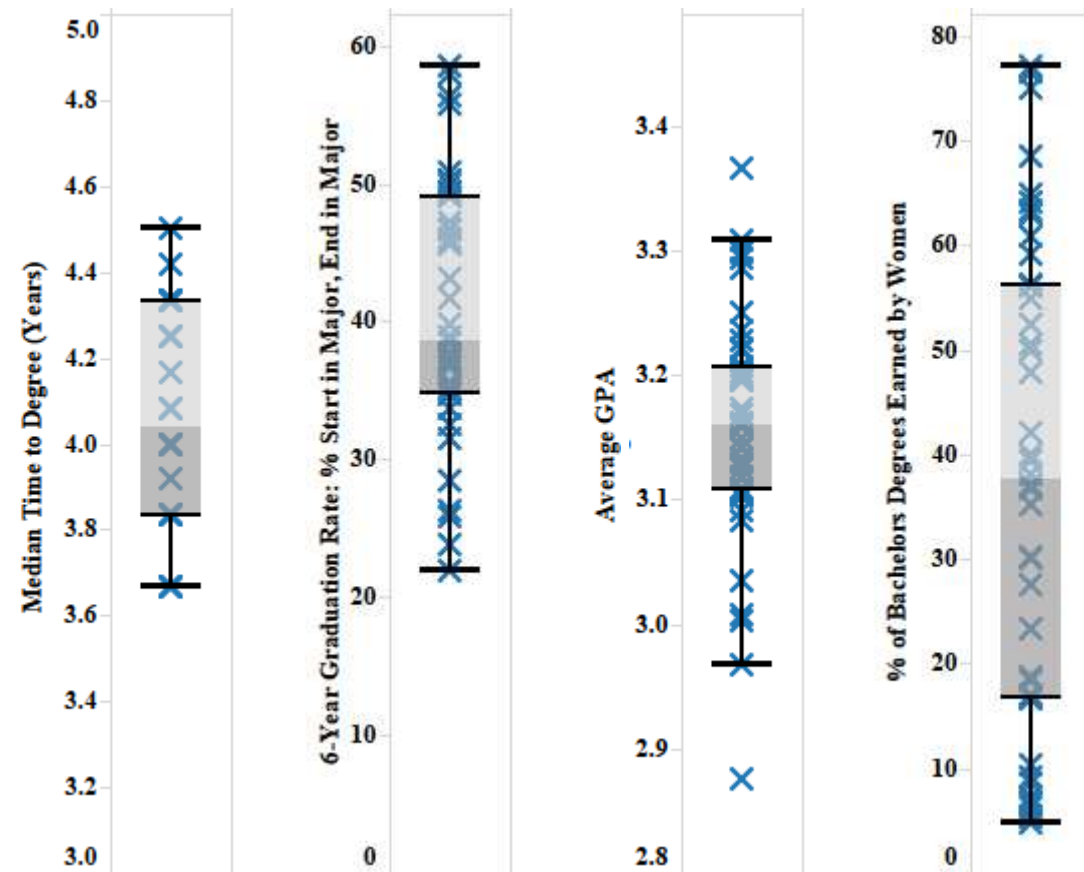
*Degree Program Outcomes*

The 21 degree programs varied considerably in their program outcomes for the four studied metrics (Table 2, Figure 6).

**Table 2.** Median and range of program outcomes for 21 degree programs.

Program Outcomes	Median (Min-Max)
Median Time to Degree	4.0 years (3.7-4.5)
Six-Year Graduation Rate	40% (20-60)
Average Graduating GPA	3.2 (2.9-3.4)
% Bachelor's Degrees Earned by Women	40% (0-80)

*Note: For students from the entering first-year cohort who started in the major and ended in the major.*



**Figure 6.** Program outcomes for 21 undergraduate degree programs.

*Curricular Choice, Balance and Degrees Program Outcomes*

Results of the Spearman’s rho correlation analysis are presented in Table 3.

**Table 3.** Spearman’s rho correlation coefficients for 21 degree programs.

<b>Program Outcomes</b>	Free Electives M=4%	Total Curricular Choice M=49%	No Curricular Choice M=63	Technical Coursework M=79%	Non-Technical Coursework M=19%
Median Time to Degree (M=4.0 years)	-.249 <sup>0.112</sup>	<b>-.559<sup>0.000</sup></b>	<b>.564<sup>0.000</sup></b>	<b>.447<sup>0.003</sup></b>	<b>-.519<sup>0.000</sup></b>
Six-Year Graduation Rate (M=40%)	<b>-.460<sup>0.002</sup></b>	-.275 <sup>0.078</sup>	.271 <sup>0.082</sup>	<b>.414<sup>0.006</sup></b>	<b>-.377<sup>0.014</sup></b>
Average GPA (M=3.2)	-.228 <sup>0.146</sup>	.045 <sup>0.778</sup>	-.043 <sup>0.787</sup>	.284 <sup>0.068</sup>	-.263 <sup>0.092</sup>
% Bachelor’s Degrees Earned by Women (M =40%)	<b>.313<sup>0.044</sup></b>	<b>.720<sup>0.000</sup></b>	<b>-.717<sup>0.000</sup></b>	<b>-.452<sup>0.003</sup></b>	<b>.558<sup>0.000</sup></b>

*Note: For students from the entering first-year cohort who started in the major and ended in the major. Superscripts indicate p-values. Shaded cells and bold numbers indicate statistical significance.*

Results of the Spearman’s rho correlation analysis demonstrated that—for the studied sampling of degree programs—more curricular choice and more non-technical coursework were correlated to less time to degree, while more technical coursework was correlated to more time to degree.

Increased choice and curricular balance were correlated to a higher percentage of bachelor’s degrees earned by women.

Higher free electives and more non-technical coursework were correlated to lower six-year graduation rates; more technical coursework was correlated to higher six-year graduation rates. Here, the disparate populations of students admitted to the College of Engineering and Applied Science versus the College of Arts and Science (Table 4) clearly presents a confounding factor; the middle 50% of students admitted to engineering have higher incoming GPAs and test scores, which translates to an increasing likelihood for graduation.<sup>11</sup> For students in the 21 studied majors who first matriculated to the University of Colorado Boulder in fall 2008, for example, average high school GPAs were more strongly correlated to six-year graduation rates (Spearman’s rho correlation coefficient=0.700, p<0.001) than the correlations detected between the curriculum metrics and six-year graduation rates (Table 4). Clearly, matched cohorts are needed to properly compare outcomes between the two colleges.

**Table 4.** The 2016 middle 50% of admitted students for the College of Engineering and Applied Science versus the College of Arts and Sciences.

Metric	College of Engineering and Applied Science	College of Arts and Sciences
High School GPA	3.87 – 4.0	3.37 – 4.0
SAT	1290 – 1470	1170 – 1350
ACT Composite	29 – 33	24 – 30

## Summary and Conclusion

Results from this pilot study were mixed as to the potential benefits of flexible, balanced engineering programs, and numerous confounding factors were present in the study. More curricular choice and more non-technical coursework were correlated to less time to degree; conversely, more technical coursework was correlated to more time to degree. Increased choice and curricular balance were correlated to a higher percentage of bachelor's degrees earned by women.

The six-year graduation rates were likely predominated by differences in academic preparedness as represented by the average incoming high school GPA; the correlations for this factor were higher than any of the curricular factors. Based solely on individual curricular factors, higher free electives and more non-technical coursework were correlated to lower six-year graduation rates; more technical coursework was correlated to higher six-year graduation rates.

The disparate admittance criteria between the College of Engineering and Applied Science and the College of Arts and Science presented a known confounding factor in this study (among other confounding factors); these results must be considered within that context. Future research across multiple institutions, such as with the 11-institution MIDFIELD dataset, and between cohorts with equivalent admission criteria is needed to continue the exploration of correlations between engineering program curricular choice opportunities, balance, and educational outcomes. If curricular choice and balance are linked to desirable program outcomes, this could be good news for engineering since customizability and flexibility organically complement ABET's outcomes-based accreditation.

## Acknowledgement

This research was made possible by the vision, generous support and funding from the S.D. Bechtel, Jr. Foundation for the *Engineering Plus* and *CU Teach Engineering* initiative. IRB 11-0651

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