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Paper ID #14423

Implicit Bias? Disparity in Opportunities to Select Technical versus Non-Technical Courses in Undergraduate Engineering Programs

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Abstract

Undergraduate engineering students are commonly afforded minimal opportunities to choose their courses as compared to their non-engineering peers on campus. In addition, many engineering programs restrict students' limited curricular choices to courses that are heavily skewed to be technical in nature, further limiting students' ability to realize a broad and balanced college education. This study extends the work of understanding course choice opportunity in engineering education by exploring the opportunities that students in U.S. News & World Report top-ranked and ABET-accredited engineering programs are afforded to choose their technical versus non-technical courses. Coursework for each of 103 programs across chemical, civil, electrical, and mechanical engineering disciplines was characterized as technical (engineering, math and natural science) or non-technical using the 2013-14 online university catalog. The programs commonly afforded students the opportunity to choose the bulk of their (limited) non-technical coursework—a median of 88%—compared to 27% of their required technical courses. Though some choice is necessary to satisfy students' innate psychological need for autonomy, too much choice is detrimental, and providing choice in a balanced manner is essential. More work is needed to better understand the optimal integration of psychologically gratifying course choice opportunity into engineering degree programs, including the psychological implications of the comparative rigidity and prescription that students encounter in their engineering, math, and natural science course selections, and comparative sovereignty over their non-technical courses.

Background

Previous studies demonstrate that undergraduate engineering students are commonly afforded minimal opportunities to choose their courses compared to their non-engineering peers on campus.[1,2] Across several dozen universities, free electives comprised a median of 24% of non-engineering programs compared to 3% of engineering programs, and non-engineering students chose a median of 74% of their total degree courses compared to 40% for engineering students.[2] It is hypothesized that the course choice disparity and low choice culture that engineering students experience are in conflict with students' psychological need for autonomy[3,4] and could be barriers to the enrollment, in-migration, and retention of undergraduate engineering students.[2] However, some programs demonstrate the possibility of a less restrictive undergraduate engineering curricular model. Highly ranked ABET Engineering Accreditation Commission (EAC)-accredited engineering programs exist that offer students levels of choice similar to programs outside of engineering. For instance, across the six engineering programs at one institution studied, engineering students were afforded a median of 19% free electives and 74% choice in coursework overall, while a second institution provided choice in a median of 71% of the coursework to earn a degree in its 14 accredited engineering programs.[2]

Further, data show that many engineering programs restrict students to curricula that are heavily skewed to primarily technical courses, limiting their ability to realize a broad and balanced college education.[2] Across top-ranked chemical, civil, electrical, and mechanical engineering degrees, a median of 78% of the coursework was technical versus 20% non-technical (remaining

2% free electives that could be either technical or non-technical).[2] This heavy bias to technical coursework is unnecessary from an accreditation standpoint. Under ABET EAC accreditation requirements in the U.S., a minimum of 2.5 years of the four-year curriculum (62.5%) must be comprised of technical courses (mathematics, natural sciences, and engineering)[5], which leaves considerable space to incorporate non-technical coursework. Formerly, ABET required a minimum of a half-year (12.5%) of humanities and social science coursework in EAC-accredited degrees. Many individuals and organizations have discussed the importance that engineers understand humanities and social sciences.[5-21] The previous study found examples of highly ranked, ABET EAC-accredited degree programs in civil, chemical, electrical, and mechanical engineering in which 33-36% of the coursework was required to be non-technical.[2]

A study comparing the approach to humanities and social science education for civil engineering programs across several universities found that the most common approach was "cafeteria style," allowing students to pick and choose their non-technical courses within some constraints.[6] For example, students were required to take one or two specific courses in addition to electives that could be chosen from various menus of approved courses. The same study found that, more than a decade after ABET dropped the required minimum of one-half year of humanities and social sciences courses, programs were still requiring approximately the same amount of coursework (14-20%) in those areas.[6] It is unclear whether these programs determined that amount of non-technical coursework to be best for an engineering education through thorough evaluation and consideration of the topic, or whether this historical throwback is an indication that few such conversations have taken place.

A survey of chemical engineering electives from nearly 100 programs revealed that "electives mirror faculty research interests," and in many cases the electives are in areas that are "active grounds for faculty research but at odds with what [an] industry survey indicated as industrial needs."[22] As the engineering profession changes, faculty find it desirous to include new material, "but it is rarely politically expedient to remove material from a curriculum."[23] An "engineering renaissance" and cultural change are needed, wherein "the merits of material are debated in the context of priorities, lifelong learning, and the quality of experience rather than historical biases."[23]

While some engineering students desire more integration of liberal arts into their engineering curriculum,[25] other engineering students find humanities, history, arts, communication, and/or culture classes "unnecessary and irrelevant" and a waste of their time.[20] This sentiment has been voiced by a number of senior engineering students at one institution who bemoan the fact that they had to "waste" their time in humanities and social science courses (even though those courses comprised only 14% of their curricula). Further, some students seem to squander their choices, selecting courses on the basis of what fills good time-periods in their schedules and/or seems easy, rather than thoughtful selections of courses of interest or potential benefit. During an accreditation visit, one reviewer questioned the popularity of a *History of Jazz* course among the students, perhaps popular as an upper-division humanities and social science course because it required no pre-requisites and had a reputation for being an "easy A."

It is worth considering whether the distaste of some engineering students towards time "wasted" on humanities or social sciences pursuits is a learned behavior, acquired by the "non-intentional

'general distribution requirements' of the university [that] are not necessarily tailored to meet the needs of students"[6] nor a thoughtfully comprised liberal core for holistically prepared engineers. Is this student response instigated and nurtured by a cultural devaluation of non-technical coursework that is reflected in minimal non-technical requirements filled with choice? Surely the presence of faculty, advisors and deans unenthusiastic about the added value of exploration of humanities and social sciences topics impacts the climate of perception towards liberal education in engineering colleges; programs that emphasize the integration of the humanities and social sciences with engineering need faculty champions, broad and overt institutional support,[26] and curriculum worthy of students' investment of time and money.

Research Questions

This study extends the work of understanding course choice opportunity in engineering education by exploring the opportunities that engineering students are afforded to choose technical versus non-technical courses. Specifically, we ask the following research questions:

- How do the required technical coursework choice opportunities in the top-ranked undergraduate engineering degree programs compare to the required non-technical coursework choice opportunities for the same degree programs? Are students permitted to choose more or less of their technical versus non-technical courses? How do the types of choices they are afforded compare to one another?
- How does course choice opportunity within required technical versus non-technical coursework vary between engineering disciplines?
- How do the technical versus non-technical course choice opportunities in engineering degree programs compare to those in the non-engineering science, technology, engineering and math (STEM) disciplines, such as chemistry, physics, and math?

Methods

Research Population

The course choice opportunities and distribution of technical versus non-technical coursework for the U.S. News & World Report[28] 103 top-ranked ABET EAC[27]-accredited undergraduate programs across 43 universities (Table 1) were examined.

Table 1. Full-time undergraduate population at 43 universities with top-ranked engineering specialty degree programs.

Full-time undergraduate population[28*]	N	Percentage of full-time undergraduate population that is ENG[28]	N	Number of ABET EAC-accredited programs at the university[30]	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

[*] *Rounded to the nearest 1,000.*

Of the 43 universities, 34 were classified as RU/VH[31] (research universities with very high research activity) and had doctoral degree programs. In this paper, these universities are referred

to as "Doctoral." The remaining nine universities did not have doctoral programs and are referred to as "No Doctoral" in this paper.

The 103 degree programs studied across the 43 universities comprised the 24 chemical, 23 civil, 26 electrical, and 30 mechanical engineering top-ranked degree programs for each discipline. Sample sizes varied due to ties in the U.S. News & World Report rankings and the unequal number of ranked programs for the No Doctoral universities. Based on the number of engineering bachelor's degrees awarded nationwide by discipline for the 2013-2014 academic year, this population of engineering programs characterizes the experience of 27% chemical, 17% civil, 25% electrical, and 21% mechanical engineering graduates.[33] As of March, 2016, this sampling represents 15% of the total number of four-year ABET-accredited programs in chemical engineering, 9% of civil, 8% of electrical, and 10% of mechanical engineering programs.[30] Although the coursework data for this study were based on the 2013-2014 academic year, these 2016 percentages provide a reference point for the scope of study since retroactive counts were not available on ABET's site.

Curricula for a total of 151 Bachelor of Arts and Bachelor of Science chemistry (BA=18, BS=30), math (BA=19, BS=31), and physics (BA=22, BS=31) degree programs spanning 41 universities that house top-ranked engineering schools were also examined, serving as non-engineering STEM comparators for technical and non-technical program content.

Defining "Technical" and "Non-Technical" Course Choice Opportunity

Technical and non-technical course choice opportunity data were gathered from the 2013-14 online university catalogs. For the purposes of this study, *technical* was defined as coursework in engineering, natural science or math, while *non-technical* was defined as coursework outside of engineering, natural science or math.

Course choice opportunities were defined as instances when degree programs afford students the freedom to choose their courses, such as free electives, humanities electives, engineering electives, or from a provided list of options. These opportunities were classified into four different choice types: 1) courses chosen from lists of options, 2) courses chosen from a single department, 3) courses chosen from more than one department, and 4) free electives. In the five-university pilot study that explored course choice opportunities for engineering versus non-engineering majors,[1] it was found that for each of these choice types, students had the opportunity to choose from a median of 3, 22, 99 and 1,292 courses, respectively, signifying increasing choice across the four categories.

Choice within Technical versus Non-Technical Coursework

The total required technical credit hours ("technical") and the total required non-technical credit hours ("non-technical") were calculated for each degree program. Credit-hour data was translated into percentages of total degree credit hours. For each degree program, the percentage of total required technical credit hours for which students were given course choices was calculated, as was the percentage of total required non-technical credit hours for which students were allotted course choices.

Sampling the Technical versus Non-Technical Choice Experience for Students

The precise choice opportunities afforded to students were detailed for the five programs with the overall (of 103 programs) highest and lowest percentages of non-technical course requirements, respectively. To ensure inclusion of multiple universities in this sampling, a maximum of one degree program was detailed per university. In the event of a tie, program selection was made based on diversifying the engineering discipline representation. For example, one university had chemical, civil, and mechanical programs that each had the lowest percentage (13%) of required non-technical coursework. Of these, only the civil engineering program (labeled program A in Table 8) was chosen for inclusion based on the fact that no other civil programs were represented in the sampling of the five programs with the overall lowest percentages of non-technical course requirements. For each highlighted degree program, each technical and non-technical course choice opportunity was grouped into one of three aforementioned categories: 1) a course chosen from a list of options; 2) a course chosen from one department, such as a "math elective"; 3) a course chosen from more than one department, such as a "humanities elective" or a "technical elective." For these 10 programs, the percentages of credit hours in each of the three categories were compared for technical versus non-technical coursework.

Statistical Analyses and Software

The data from this study were based on course counts; as such, nonparametric statistical tests were used for all analyses. The Friedman ANOVA test was used to look for statistically significant differences between more than two groups of dependent data; the Wilcoxon Signed Rank test was used to detect differences between two groups of dependent data. The Kruskal-Wallis test was used to detect statistically significant differences between more than two groups of independent data; Mann-Whitney U tests were used to look for differences between two groups of independent data. Spearman Rank Correlation tests were used to test for coefficients of association between ordinal variables. A table of critical values for Spearman's rho was used to determine statistical significance based on sample size.[32] Data were compiled in Microsoft Excel 2013. The Friedman ANOVA analyses were conducted using The Statistical Package for the Social Sciences (SPSS) 23; all other statistical analyses were performed using MVPstats. In all cases, two-tailed significance levels of $\alpha = 0.05$ were used.

Results

Technical versus Non-Technical Coursework Requirements

The percentages of total degree credit hours comprised of required technical, required non-technical, and free elective courses for each of the degree program types are presented in Table 2.

Table 2. Percentage of degree comprised of required technical courses, required non-technical courses, and free electives across 103 degree programs spanning four engineering disciplines.

Course-type	Value	Chemical (n = 24)	Civil (n = 23)	Electrical (n = 26)	Mechanical (n = 30)	151 Math, phys, chemistry comparators
Technical	Max	85.9	82.0	86.5	86.4	78.3
	Median	78.9	78.1	76.2	80.9	52.5
	Min	64.2	62.2	61.9	63.9	24.2
Non-technical	Max	35.6	35.6	33.9	35.6	50.0
	Median	19.1	20.0	19.8	19.5	25.9
	Min	12.5	12.5	13.5	12.5	17.5
Free electives	Max	11.9	14.4	19.0	19.4	50.0
	Median	0.0	0.6	2.7	2.3	18.4
	Min	0.0	0.0	0.0	0.0	0.0

Across disciplines, this population of 103 engineering degree programs had technical coursework requirements that comprised a median of 78% of total degree credit hours, versus 20% non-technical coursework requirements. No differences were detected in the percentage of total degree program comprised of required technical coursework (Kruskal-Wallis p=0.256) or non-technical coursework (Kruskal-Wallis p=0.542) across the four engineering disciplines.
Free electives could be used by the students toward technical or non-technical coursework, per their own preference, but these options are limited in nearly all of the degree programs.
It is evident from Table 2 that the 151 chemistry, physics, and math comparator programs tended to require substantially less technical coursework, more non-technical coursework, and considerably more free elective opportunities than the engineering programs.

Choice in Technical versus Non-Technical Coursework Requirements
The percentages of required technical versus non-technical coursework that offer students choices for the engineering degree programs are presented in Figure 1 and Table 3. Box-and-whisker plots are used to present the data, displaying the median (the center of the box), the first quartile (lower extent of the box), third quartile (upper extent of the box), maximum (upper extent of whisker) and minimum (lower extent of whisker). In some cases, statistical outliers extend beyond the whiskers.

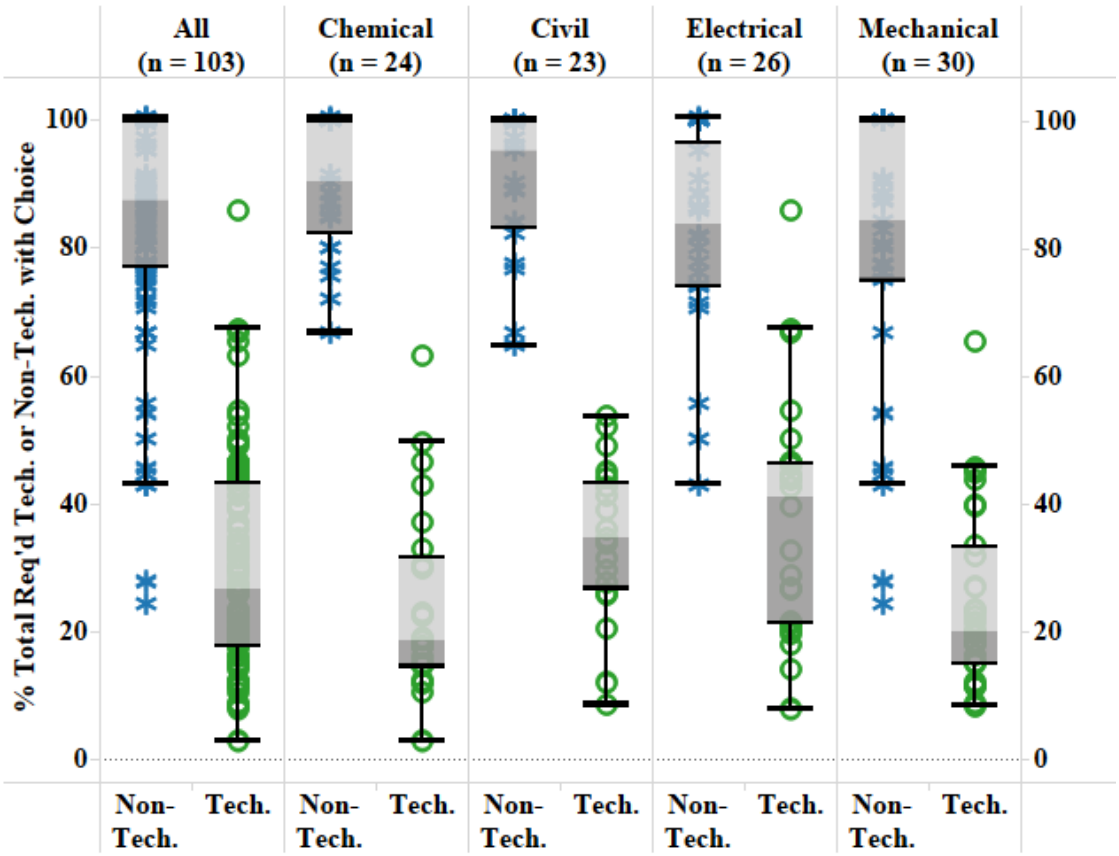

Figure 1. Comparing the percentages of required courses that offer students choices for technical versus non-technical courses across engineering programs.

Table 3. Median percentage choice values for required technical versus non-technical coursework and Wilcoxon Signed Rank p-values.

Engineering Program-Type				
All	**Chemical**	**Civil**	**Electrical**	**Mechanical**
$\tilde{x}_{\text{Non-Tech}} = 87.5$ $\tilde{x}_{\text{Tech}} = 26.7$ **p = 0.000***	$\tilde{x}_{\text{Non-Tech}} = 90.3$ $\tilde{x}_{\text{Tech}} = 18.5$ **p = 0.000***	$\tilde{x}_{\text{Non-Tech}} = 95.2$ $\tilde{x}_{\text{Tech}} = 34.6$ **p = 0.000***	$\tilde{x}_{\text{Non-Tech}} = 83.8$ $\tilde{x}_{\text{Tech}} = 41.1$ **p = 0.000***	$\tilde{x}_{\text{Non-Tech}} = 84.2$ $\tilde{x}_{\text{Tech}} = 20.0$ **p = 0.000***

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

As shown in Table 3, statistically significant differences in the percentages of required technical versus non-technical credit hours with choice were detected for each of the four engineering program types. All but two of the 103 engineering programs afforded students more opportunities (by percentage) to select courses to meet non-technical requirements than their technical requirements (median 56% higher for non-technical than technical). All but six of the programs afforded students the freedom to choose over 50% of their non-technical coursework, with a median across all disciplines of 88%. These same students, however, were provided with course choices for a median of just over a quarter (27%) of their required technical courses—in sharp contrast to the choice afforded them among their non-technical courses.

Results of a Kruskal-Wallis test revealed a statistically significant difference in the percentage of required technical coursework with choice across the four engineering disciplines (p=0.004). Mann-Whitney U post hoc tests indicated that the civil and electrical programs afforded students more choice in their technical coursework than the chemical and mechanical programs.
No differences were detected in the percentage of required non-technical coursework with choice across the four engineering disciplines (Kruskal-Wallis p=0.165).

For comparison, the 151 chemistry, math, and physics comparator programs provided course choices for a median of 21% of required technical coursework versus 31% for non-technical coursework. Relating these results to the median course choice percentages from the 103 engineering programs of 27% for technical coursework versus 88% for non-technical coursework, it seems that the disparity in course choice opportunities between technical and non-technical requirements may be more measured in non-engineering STEM disciplines.

Technical versus Non-Technical Choice across Engineering Disciplines at the Same University
Fifteen universities offered all four of the studied engineering disciplines: degree programs in chemical, civil, electrical, and mechanical engineering. Within this population of 15 universities, a difference was detected in the percentage of total required technical credit hours with choice for the four engineering program types (Friedman ANOVA p=0.004, Table 4). Wilcoxon Signed Rank post hoc tests indicated that—even within the same university—the civil and electrical programs afforded students more choice in their technical coursework than the chemical and mechanical programs. These results echo those found for the engineering disciplines across the population of 103 programs previously discussed.

Table 4. Median percentage of total required technical credit hours with choice and Friedman ANOVA p-value for four engineering program-types offered at 15 universities.

Engineering Program-Type				**Friedman ANOVA**
Chemical	**Civil**	**Electrical**	**Mechanical**	
$\tilde{x}_{\text{Chem}} = 18.5$	$\tilde{x}_{\text{Civil}} = 35.3$	$\tilde{x}_{\text{Elect}} = 44.8$	$\tilde{x}_{\text{Mech}} = 19.4$	**p = 0.004***

**Statistically significant p-value ($\alpha = 0.05$).*
Note: See Appendix A for associated figure.

Within these same programs at the 15 universities, no difference was detected in the percentage of total required non-technical credit hours with choice for the four engineering program-types (Friedman ANOVA p=0.258, Table 5), again echoing the findings for the population of 103 programs, and suggesting that all of the disciplines tend to afford substantial choice to students in the selection of required non-technical courses.

Table 5. Median percentage of total required non-technical credit hours with choice and Friedman ANOVA p-value for four engineering program-types offered at 15 universities.

Engineering Program-Type				Friedman ANOVA
Chemical	**Civil**	**Electrical**	**Mechanical**	
$\tilde{x}_{Chem} = 100.0$	$\tilde{x}_{Civil} = 96.7$	$\tilde{x}_{Elect} = 98.8$	$\tilde{x}_{Mech} = 88.5$	**p = 0.258**

Note: See Appendix A for associated figure.

Technical versus Non-Technical Choice for Doctoral versus No Doctoral Universities

The percentages of total required technical and non-technical credit hours with choice across the four engineering program-types were compared for Doctoral versus No Doctoral universities. The civil, electrical, and mechanical engineering programs at the universities without doctoral programs were found to have less choice in their required technical coursework than those same engineering program types at the universities with doctoral programs (Mann-Whitney U p_{civil}=0.044, $p_{electrical}$=0.003, $p_{mechanical}$=0.022, Table 6). No statistically significant difference was detected in the percentage of required technical coursework with choice between the chemical engineering programs at the Doctoral versus No Doctoral institutions (p=0.299).

Table 6. Median percentage of required technical credit hours with choice 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**
$\tilde{x}_{Doc} = 31.5$ $\tilde{x}_{No\ Doc} = 17.9$ **p = 0.000***	$\tilde{x}_{Doc} = 18.8$ $\tilde{x}_{No\ Doc} = 14.5$ **p = 0.299**	$\tilde{x}_{Doc} = 37.5$ $\tilde{x}_{No\ Doc} = 25.5$ **p = 0.044***	$\tilde{x}_{Doc} = 43.9$ $\tilde{x}_{No\ Doc} = 17.8$ **p = 0.003***	$\tilde{x}_{Doc} = 22.7$ $\tilde{x}_{No\ Doc} = 16.1$ **p = 0.022***

**Statistically significant p-value (α = 0.05).*
Note: See Appendix B for associated figure.

Less choice also existed among the non-technical courses at institutions without doctoral programs (median 46%) compared to those with doctoral programs (median 87%) for mechanical engineering programs (p=0.034). Differences between choice in non-technical courses were not significant for Doctoral and No Doctoral programs in chemical, civil, and electrical engineering (Table 7).

Table 7. Median percentage of required *non-technical* credit hours with choice 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**
$\tilde{x}_{\text{Doc}} = 88.0$ $\tilde{x}_{\text{No Doc}} = 86.5$ **p = 0.163**	$\tilde{x}_{\text{Doc}} = 90.3$ $\tilde{x}_{\text{No Doc}} = 87.8$ **p = 0.776**	$\tilde{x}_{\text{Doc}} = 89.7$ $\tilde{x}_{\text{No Doc}} = 100.0$ **p = 0.108**	$\tilde{x}_{\text{Doc}} = 81.8$ $\tilde{x}_{\text{No Doc}} = 86.5$ **p = 0.616**	$\tilde{x}_{\text{Doc}} = 87.4$ $\tilde{x}_{\text{No Doc}} = 45.5$ **p = 0.034***

**Statistically significant p-value ($\alpha = 0.05$).*
Note: See Appendix B for associated figure.

The Technical versus Non-Technical Choice Experience

The specific choice opportunities afforded to students were detailed for the five programs, with the overall (of 103 programs) highest and lowest percentages of non-technical course requirements, respectively (Table 8).

Table 8. Course choice opportunities for degree programs with the highest and lowest percentages of non-technical course requirements.

Program alias; eng. discipline	Public / private; Carnegie Class.[31]	Req'd tech / non-tech degree program course-work	% of total degree credit hours	% of credit hours with choice	% req'd credit hours chosen from a list of options	% req'd credit hours chosen from one dept.	% req'd credit hours chosen from > one dept.
A Civil	Public RU/VH	Non-tech.	13	100	0	0	100
		Technical	78	39	39	0	0
B Mech.	Public RU/VH	Non-tech.	13	82	0	0	82
		Technical	87	22	15	7	0
C Mech.	Public Mast. L	Non-tech.	14	83	83	0	0
		Technical	86	8	8	0	0
D Mech.	Public RU/VH	Non-tech.	15	68	0	0	68
		Technical	83	27	27	0	0
E Mech.	Public RU/VH	Non-tech.	16	100	0	0	100
		Technical	84	19	4	0	15
V Mech.	Private RU/VH	Non-tech.	24	100	0	0	100
		Technical	64	45	45	0	0
W Elect.	Public RU/VH	Non-tech.	26	70	51	19	0
		Technical	74	44	11	21	12
X Elect.	Private RU/VH	Non-tech.	26	97	31	0	66
		Technical	67	20	12	8	0
Y Elect.	Public RU/VH	Non-tech.	27	91	7	0	84
		Technical	73	54	43	11	0
Z Civil	Private RU/VH	Non-tech.	36	100	31	0	69
		Technical	62	54	54	0	0

Note: RU/VH = Research universities (very high research activity);
Master's L = Master's colleges and universities (larger programs)

In each case, degree programs afforded choice in greater percentages of their required non-technical coursework than their technical coursework. For choice opportunities in both technical and non-technical courses, programs varied in the choice types offered. Spearman's rho correlation coefficients for technical versus non-technical course choice opportunity data from Table 8 are presented in Tables 9 and 10.

Table 9. Spearman's rho correlation coefficients for technical course choice opportunity.

	% Req'd *technical* credit hours chosen from a list of options	% Req'd *technical* credit hours chosen from one dept.	% Req'd *technical* credit hours chosen from > one dept.
% Total degree composed of req'd *technical* credit hours	**-0.673***	-0.096	0.199
% Req'd *technical* credit hours with choice	**0.845***	0.209	-0.217

**Statistically significant, $\alpha = 0.05$*

Table 10. Spearman's rho correlation coefficients for non-technical course choice opportunity.

	% Req'd *non-tech.* credit hours chosen from a list of options	% Req'd *non-tech.* credit hours chosen from one dept.	% Req'd *non-tech.* credit hours chosen from > one dept.
% Total degree composed of req'd *non-technical* credit hours	0.447	0.234	-0.170
% Req'd *non-technical* credit hours with choice	-0.231	-0.419	**0.679***

**Statistically significant, $\alpha = 0.05$*

A significant positive correlation was detected between the percentage of required technical credit hours with choice and the percentage of technical coursework chosen from a list of options, suggesting that the more technical course choice is afforded to engineering students, the more they make those choices from constrained lists of options (in many cases these lists only offer inconsequential choices, such as between two calculus classes). Conversely, with non-technical requirements, a significant positive correlation was detected between the percentage of required non-technical credit hours with choice and the percentage of non-technical coursework chosen from more than one department, suggesting that the more non-technical course choice is afforded to engineering students, the more freedom they have to make those choices across multiple departments. These bifurcated correlations may suggest that engineering students not only choose greater percentages of their non-technical than technical coursework, but they are also afforded more expanded choices within their non-technical choice opportunities.

In addition, a statistically significant negative correlation (-0.171, not presented in Table 9 in the interest in space) was found between the percentage of total degree comprised of required technical coursework and the percentage of that coursework with choice, perhaps suggesting that engineering programs with more technical requirements afford students less choice than programs with fewer technical requirements. A significant negative correlation was detected between the percentage of total degree comprised of technical coursework and the percentage of that coursework that is chosen from a list of options—again a potential indication that

engineering programs with more technical requirements afford students with less technical course choice.

For these same 10 programs, the percentages of required technical versus non-technical credit hours that afforded the three respective choice types are presented in Figure 2 and Table 11.

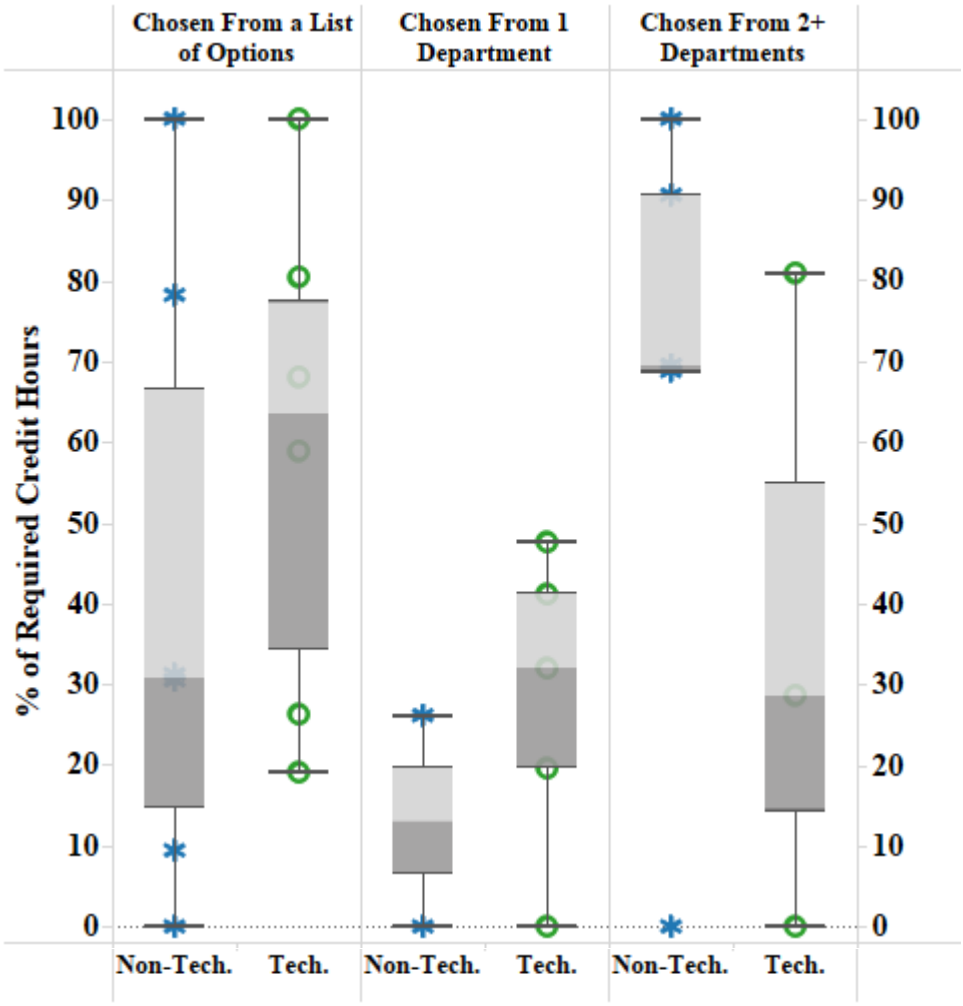

Figure 2. Comparing the choice types for required technical versus non-technical courses across 10 engineering programs.

Table 11. Median percentages of technical versus non-technical courses with choice for three choice types across 10 engineering programs and their Wilcoxon Signed Rank p-values.

% Req'd coursework chosen from a list	% Req'd coursework chosen from one department	% Req'd coursework chosen from 2+ departments
$\tilde{x}_{\text{Non-Tech}} = 30.8$ $\tilde{x}_{\text{Tech}} = 63.4$ p = 0.889	$\tilde{x}_{\text{Non-Tech}} = 13.0$ $\tilde{x}_{\text{Tech}} = 32.0$ p = 0.068	$\tilde{x}_{\text{Non-Tech}} = 69.6$ $\tilde{x}_{\text{Tech}} = 28.6$ p = 0.345

The median percentage for choice in required technical coursework was highest for courses chosen from a list, almost two times higher than for courses chosen from one or more departments. Again, in many cases these "lists" simply consisted of multiple versions of a statistics course, for example, or multiple proficiency courses in an engineering sub-discipline. Conversely, the highest median percentage value for choice in required non-technical coursework was found for courses chosen from more than two departments, such as "humanities electives." Comparing these median values, it seems that these 10 degree programs afforded their students greater freedom in their non-technical course choice types than their technical course choice types. However, no statistically significant differences were detected between the percentages of required technical versus non-technical credit hours for which students are afforded three types of course choices (see Wilcoxon Signed Rank p-values in Table 11).

Statistically significant differences were also not detected in the percentages of technical credit hours with choice across choice types (Friedman ANOVA p=0.266), nor in the percentages of technical credit hours with choice across choice types (Friedman ANOVA p=0.093). Rather than suggesting patterns in the technical versus non-technical course choice types afforded to engineering students, these results and the spread of values evident in Figure 2 are instead suggestive of diverse manifestations of technical and non-technical course choice opportunities in undergraduate engineering programs.

Discussion

Findings from this study indicate that, across engineering disciplines from the studied population of programs, students are routinely afforded more opportunities (by percentage) to select courses to meet non-technical requirements than technical requirements. In the studied programs, most students choose the bulk of their non-technical coursework, a median of 88%, compared to choice opportunities in a median of just over one-quarter of their technical coursework. And, in some cases engineering students not only choose greater percentages of their non-technical than technical coursework, but they are also afforded more expanded choices within their non-technical choice opportunities. This bifurcation of technical versus non-technical choice type was seen in some programs that provided students with tiresome lists from which to choose technical coursework (such as "choose one of the following three statistics courses") compared to expanded, loose choice opportunities in non-technical coursework (such as "humanities electives").

The differences in the choices allocated to students in the selection of their engineering degree program technical courses versus non-technical courses are worthy of reflection. Certainly, many technical courses that are foundational to engineering programs, such as calculus, physics, and core engineering courses, do not lend themselves well to meaningful course choice opportunities. However, the same could be said for non-technical coursework that should be deemed essential for the education of any engineer, such as specific ethics and writing courses. Within arts and sciences degrees, the types of general education courses from which students may select are often classified into particular learning outcomes, such as the "content areas of study" in the core curriculum at the University of Colorado Boulder that include historical context, human diversity, United States context, literature and the arts, contemporary societies, ideals and values, and natural science. This level of course organization is noticeably absent from the liberal arts curriculum of many engineering programs, including the engineering programs at CU Boulder.

Yet, in the absence of detailed requirements from ABET as to what constitutes a "general education component that complements the technical content of the curriculum and is consistent with the program and institution objectives,"[5] the non-technical essentials—how many courses and of what—are largely at the discretion of university engineering educators. The result is a diverse implementation of general education requirements for engineering students;[2] perhaps this exceedingly flexible accreditation approach to general education has in some cases also yielded a more laissez-faire approach to prescribing specific non-technical coursework, resulting in comparatively more choice in the non-technical engineering program coursework.

It is worth asking, therefore, whether these disproportionate choice allocations are a window into unfavorable value-judgments placed on the general education component in some engineering colleges or departments (as in, "we don't care what non-technical classes you take, so you can pick"), or rather, whether the studied curricular choice opportunities were deliberately constructed by attentive educators that value the entirety of an engineering education and simply had other motivations behind the disproportionate technical versus non-technical course choice allocations. Perhaps an unstated bias exists that choice equates to less "rigor," and so the unintended message to students of differential choice in technical versus non-technical coursework may be that knowledge and courses in non-technical subjects are comparatively unimportant. Values are inherent in engineering design; so just as the technical content of an engineering program is (hopefully) carefully scaffolded, "the same intentionality and evaluation should be undertaken for the liberal component of a student's undergraduate experience."[6]

Though some choice is necessary, too much choice can be detrimental;[29] thus, providing choice in a balanced manner is essential. Engineering educators must be mindful when integrating course choice opportunities into degree programs, alert to the psychologically paralyzing consequences of providing too much choice[29] while supporting students' psychological need for autonomy via carefully constructed choice opportunities that nurture intrinsic motivation.[3,4] The specific, practical and evidence-based application of the academic notion of choice to *course choice opportunity* in undergraduate engineering programs is largely uncharted. More work is needed to better understand the optimal integration of psychologically gratifying course choice opportunity into engineering degree programs, including the psychological implications of students encountering comparative rigidity and prescription in their engineering, math and natural science course selections, with comparative sovereignty over their non-technical courses. Are injurious biases unintentionally communicated? Is today's prevailing course choice disparity beneficial or harmful? How does such disparity communicate what engineering educators think is really important to the development of a competent globally aware engineer? And, from an outcomes perspective, how does that compare to what industry and government declare they need in today's engineers?

Acknowledgement
This work was made possible by the S.D. Bechtel, Jr. Foundation whose vision, generous support and funding made this research possible as part of the *Engineering Plus* and CU Teach Engineering initiative. IRB 11-0651

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Appendix A: Percentages of total required technical and non-technical credit hours with choice for four engineering program-types at 15 universities.

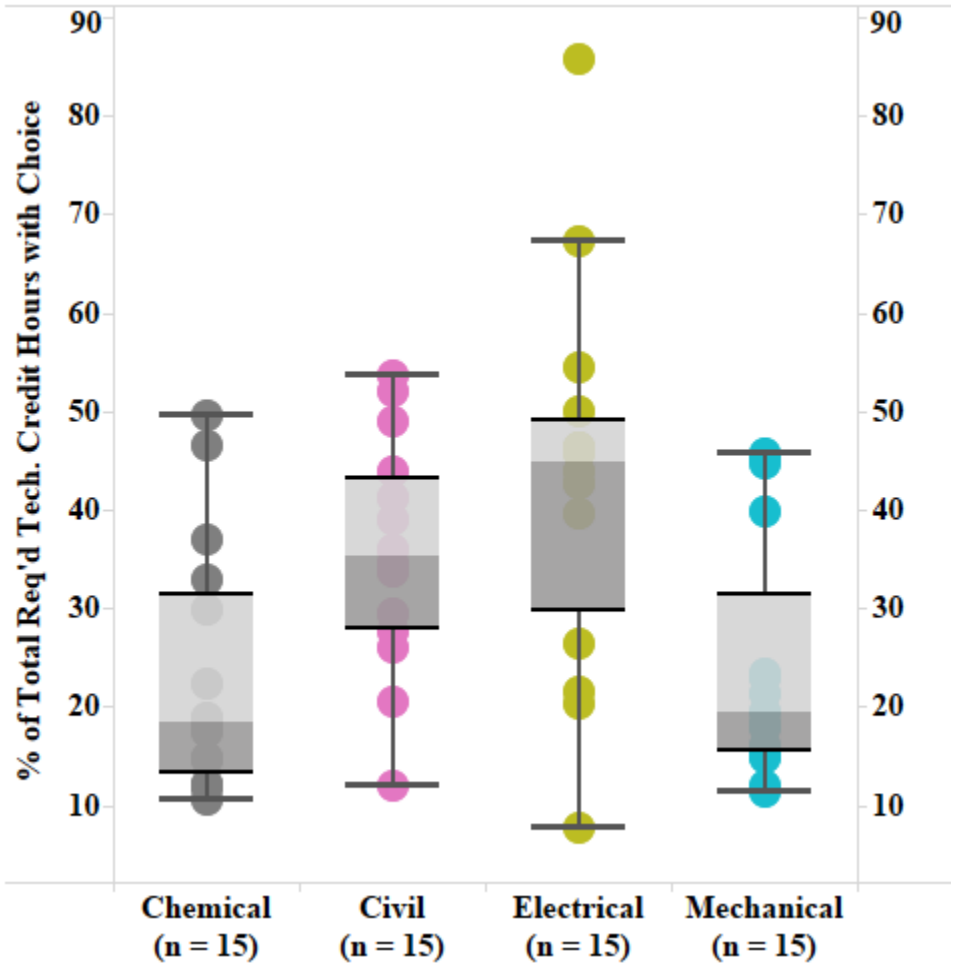

Figure A.1. Percentage of total required technical credit hours with choice for four engineering program types at 15 universities.

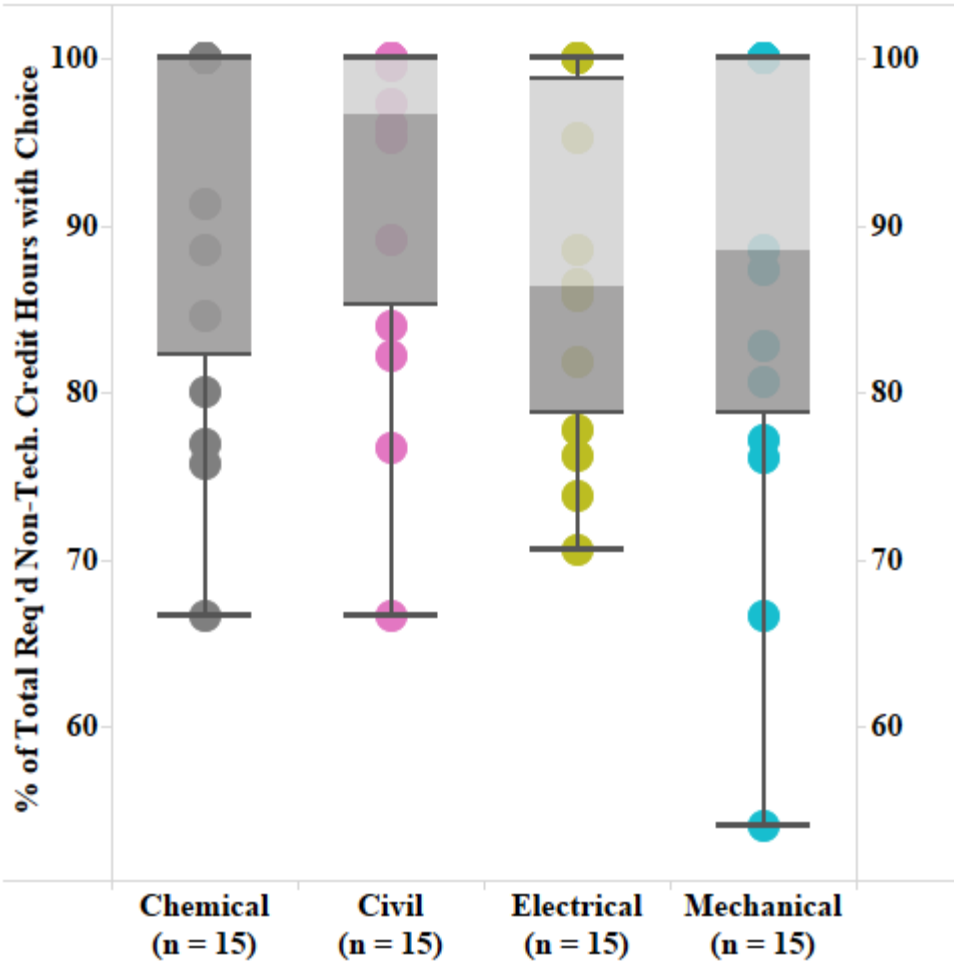

Figure A.2. Percentage of total required non-technical credit hours with choice for four engineering program types at 15 universities.

Appendix B: Percentages of total required technical and non-technical credit hours with choice for Doctoral versus No Doctoral universities across four engineering program types.

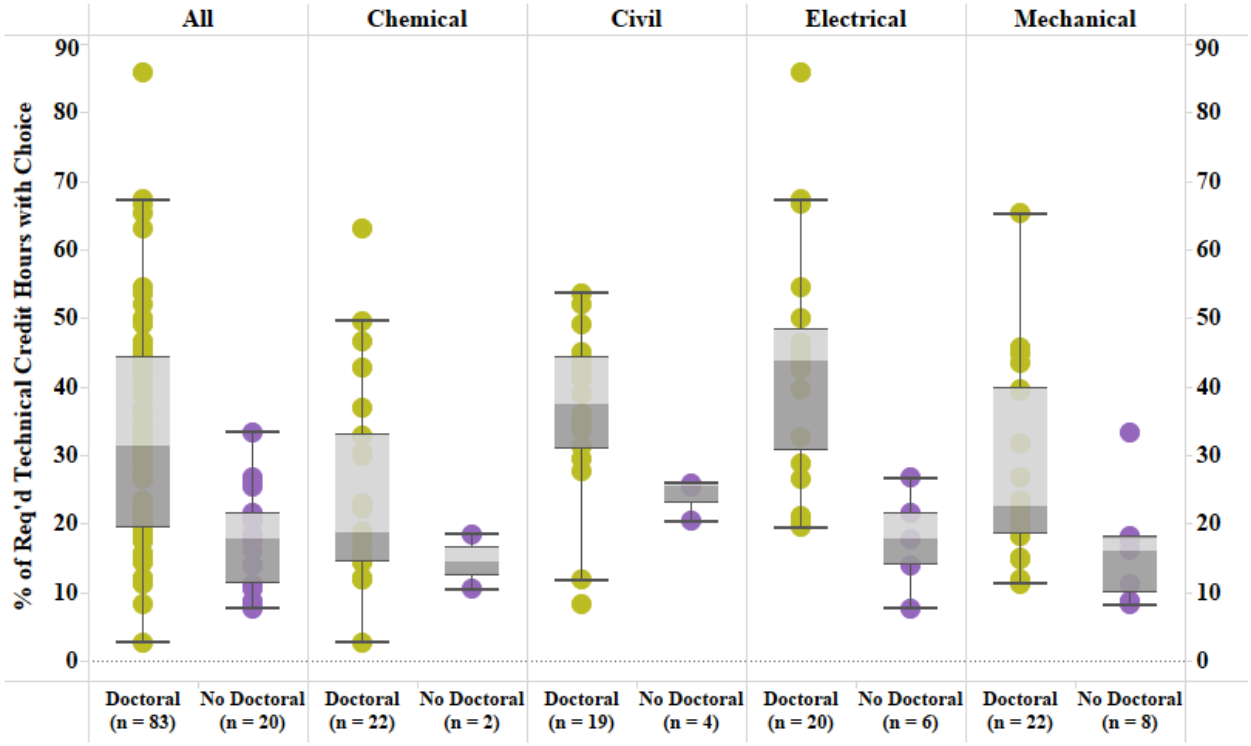

Figure B.1. Percentage of required technical credit hours with choice for Doctoral versus No Doctoral universities across four engineering program types.

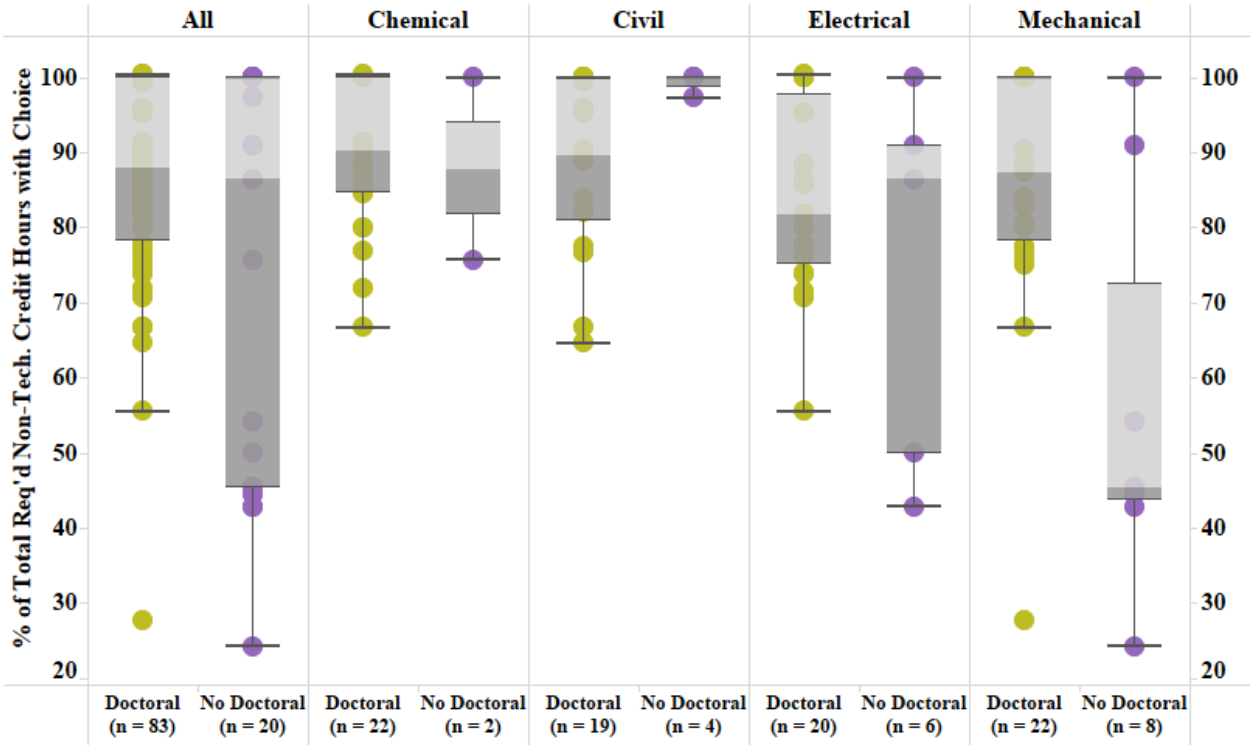

Figure B.2. Percentage of required non-technical credit hours with choice for Doctoral versus No Doctoral universities across four engineering program types.