Probing Correlations Between Undergraduate Engineering Programs' Customizability and Gender Diversity

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Abstract

A low percentage of women students is prevalent in most engineering disciplines, resulting in a loss of diverse input and perspectives to the profession. Previous studies demonstrated that engineering programs commonly offer students few opportunities to choose their own courses as compared to their non-engineering campus peers. Preliminary research, survey, and enrollment findings led to the question as to whether the extent of curricular flexibility and customizability in an engineering program may differentially matter to women students. This preliminary quantitative study explored whether increased course choice opportunities (such as free electives, technical electives, etc.) correlated to higher enrollments of women and/or bachelor's degrees earned by women in a sampling of chemical, civil, electrical and mechanical engineering programs. Percentages of total degree credit hours comprised of free electives and course choices were delineated for 84 highly regarded engineering programs. Correlations were found between curricular choice and percentage female enrollments and bachelor's degrees awarded to women. The results point to the need for additional research to ascertain whether providing more customizable degree program options may be a means of attracting more women to undergraduate engineering programs.

Introduction

Though women earned more than 50% of the bachelor's degrees awarded in the United States (NCES, 2015), from 2010-2013 they earned an average of only19% of the undergraduate engineering bachelor's degrees, compared to 20% in physics, 42% in math and statistics, 49% in chemistry and 59% in the biological sciences.[1] Wide disparity in gender diversity exists amongst engineering disciplines; in 2015, the percentage of bachelor's degrees awarded to women ranged from 11% in computer engineering to 50% in environmental engineering.[2] Numerous studies indicate that in most engineering disciplines no differential attrition exists by gender,[3,4,5,6,7] and that the large gender disparities among graduates are due to low initial enrollment of women in engineering.

Why are some undergraduate science, technology, engineering and math (STEM) disciplines much closer to gender parity than others, including many engineering disciplines? This question is complex and many variables likely play a role. One variable explored in this study is the presence (or absence) of curricular choice (i.e. the ability to customize one's curricular experience) in undergraduate degree programs, which varies substantially across engineering and non-engineering STEM disciplines.[8,9,10] In a study spanning over 500 degree programs across dozens of universities, engineering students were afforded a median of 3% of their curriculum as free electives, as compared to physics, chemistry and math students at the same universities whose degree programs were comprised of 15%, 17% and 22% free electives, respectively.[10] In other words, many undergraduate engineering programs provide their students with substantially less choice in their coursework than their non-engineering STEM counterparts, some of which experience markedly higher percentage enrollments of women. Is there a correlation?

In recent decades, curricular choice increased in American colleges and universities, yielding customizable degree programs as a common undergraduate student experience in the U.S.[11] This curricular evolution complements a fundamental tenet of self-determination theory, which states that autonomy is a fundamental psychological need, and that providing people with choices can impact their satisfaction and motivation.[12,13]

Findings are mixed in terms of whether choice is differentially important to women versus men in various contexts. For example, no gender differences were found in a study that demonstrated the deleterious use of controlling techniques versus non-controlling directives in solving analytic reasoning problems,[14] while in another study, men and women were found to differ in the "quantity of motivation and the quality of motivation" with autonomy holding differential importance to women.[15] Providing choice in activity for physical education (PE) classes, known to suffer from a population of "disengaged" girls—due to a "combination of psychological, social, and environmental barriers"—has been shown to increase young women's engagement in, and positive perceptions of, PE.[16] Each of these studies deal with smaller-scale freedoms, within the context of a given task or class, but less is known about possible gender differences with respect to larger-scale freedoms, such as choice in the coursework that comprises one's undergraduate degree.

Within engineering, there is some limited, preliminary data suggesting that increased curricular flexibility and customizability may be differentially appealing to women. In 2012, 24% (n=821) of the University of Colorado Boulder undergraduate engineering students responded to a survey, wherein more women (24%) than men (17%) "strongly agreed" that they would "like the flexibility to customize [their] engineering degree programs through an individualized, negotiated curriculum" (chi-square p=0.001).[9]

The Massachusetts Institute of Technology (MIT) offers students a traditional mechanical engineering degree program (Course 2) as well as a customizable mechanical engineering degree program (Course 2-A) that promotes flexibility and an opportunity to tailor the curriculum to meet individual student desires.[17] In a comparison of the two degree programs from 2010-2015, MIT's customizable mechanical engineering program awarded a higher median percentage of bachelor's degrees to women (43%) than the traditional mechanical engineering program (37%), bringing it on par with the median for the college overall for the same years (43%).[2]

Does curricular choice play a role in the complex puzzle of the generally low representation of women within many engineering disciplines? In this paper, the authors explore curricular customizability as one possible component of what is likely a large set of factors that contribute to the comparative lack of women choosing to major in some engineering disciplines. Specifically, this preliminary study explores whether undergraduate engineering programs affording students comparatively more course choice opportunity have differentially higher percentage enrollments of women and/or award a higher percentage of their bachelor's degrees to women.

Methods

The course choice opportunities for 84 ABET EAC-accredited undergraduate engineering degree programs spanning 35 universities (12 private, 23 public) were delineated using the 2013-2014 online university catalogs. The studied population of programs represents the 2015 U.S. News & World Report top-ranked undergraduate programs in chemical (n=22), civil (n=20), electrical (n=20), and mechanical engineering (n=22) degree programs; sample sizes varied due to ranking ties as well as the removal of degree programs from the data set that awarded fewer than 20 bachelor's degrees in 2013-2014. The engineering rankings were based solely on peer assessment surveys.[18] Data for percentage female enrollment and bachelor's degrees awarded to women were gathered for each program from the American Society for Engineering Education online college profiles.[19]

The selected rankings were specific to engineering schools in which doctoral programs were offered, so as to filter for larger degree programs that would be less prone to annual fluctuations in percentage female enrollments and bachelor's degrees awarded. Each of the studied degree programs was housed in a university with the Carnegie Classification[20] of "Research Universities (very high research activity)" (RU/VH).

The chosen engineering disciplines were representative of a range of the percentage of engineering bachelor's degrees awarded to women by discipline in 2013: chemical engineering (32%), civil engineering (21%), mechanical engineering (13%), and electrical engineering (12%).[2] These disciplines also award a large percentage of the total engineering bachelor's degrees in the U.S. (chemical=9%; civil=11%; electrical=11%; mechanical=24%) relative to smaller disciplines that have greater percentages of women graduates (such as environmental engineering, which only awards 1% of the engineering bachelor's degrees in the U.S., but half of those degrees are earned by women).[2]

Two metrics were used to quantify course choice opportunity for each degree program: 1) the percentage of total degree credit hours that were free electives (i.e., no restrictions were placed on the course[s] students could choose) and 2) the percentage of total degree credit hours for which students were provided any amount of choice in their coursework, including free electives, technical electives, humanities electives, etc., and any opportunities to choose courses from menus or lists of options. More information is provided in Forbes, 2015.

Data from this study were ordinal in nature; therefore, median (M) values are reported and non-parametric statistical analyses were used. Kruskal-Wallis (a test for ordinal data analogous to the ANOVA test for continuous data) tests were used to look for differences across the four engineering program types; Mann-Whitney U (a test for ordinal data analogous to the t-test for continuous data) tests were used as post-hoc tests to look for differences between two engineering disciplines. Dispersion analyses, comparing the spread of free electives and total choice percentages for engineering disciplines, were conducted by running Kruskal-Wallis tests on the absolute deviation from median (ADM) scores. The Spearman's rho correlation statistical test (a test for ordinal data analogous to the Pearson correlation test for continuous data) was used to test for coefficients of association between free elective and total choice percentages for each of the engineering programs and 1) percentage female enrollments and 2) the percentage of bachelor's degrees awarded to women. Statistical analyses were performed using MVPstats; $\alpha = 0.05$.

Results

Free Electives

At the median across all engineering programs studied, students were afforded 1% of their degree program as free electives (M_{chem}=0%, M_{civil}=0%, M_{elect}=2%, M_{mech}=3%; Kruskal-Wallis $p=0.412$). Almost half ($n=41$) of the 84 engineering programs offered no free electives to their engineering students: 14 chemical engineering, 10 civil engineering, nine electrical engineering, and eight mechanical engineering degree programs. Conversely, 12 of the programs offered students at least 10% free electives as a part of their undergraduate experiences (three chemical engineering, two civil engineering, four electrical engineering, and three mechanical engineering degree programs), a marked difference in collegiate academic experiences as compared to engineering students who never get to choose free electives over the course of their undergraduate careers.

The dispersion analysis identified a statistically significant difference (Kruskal-Wallis p=0.006) in the spread of free elective percentages across the four engineering disciplines; Mann-Whitney U post hoc tests indicated that the chemical engineering programs had the least variability.

Total Choice

At the median across the 84 engineering programs, students were provided with some choice in almost half (47%) of their coursework (M_{chem}=34%, M_{civil}=51%, M_{elect}=53%, M_{mech}=37%; Kruskal-Wallis p=0.001). Mann-Whitney U post hoc tests revealed that the chemical and mechanical engineering programs had less total choice than the civil and electrical engineering programs. The program with the lowest total choice still offered students some choice in almost one-quarter (24%) of the overall degree. Unlike the results of the free electives dispersion analysis, no difference was detected in the spread of total choice percentages across the four engineering disciplines (Kruskal-Wallis p=0.329).

Enrollments and Bachelor's Degrees Earned by Women

A wide range of percentage female enrollments (Kruskal-Wallis p=0.000) and bachelor's degrees awarded to women (Kruskal-Wallis p=0.000) was found across programs (Table 1). The chemical and civil engineering programs had comparable percentage female enrollments (Mann-Whitney U p=0.754) and degrees earned by women (Mann-Whitney U p=0.118); similarly, the electrical and mechanical engineering programs had comparable percentage female enrollments (Mann-Whitney U p=0.834) and bachelor's degrees earned (Mann-Whitney U p=0.456). The chemical and civil programs had higher percentage female enrollments and degrees earned by women than the civil and electrical programs. The median percentages of bachelor's degrees earned by women for each of the engineering disciplines (M_{chem}=32%, M_{civil}=28%, M_{elect}=14%, M_{mech}=15%) ranged somewhat in proximity to the national averages (chemical=32%, civil=21%, electrical=12%, mechanical=13%) (ASEE, 2013).

Choice Versus Female Enrollments and Bachelor's Degrees Earned by Women

Spearman's rho correlation coefficients for tests run between the percentage free elective and total choice values for the 84 engineering programs and the programs' corresponding percentage female enrollments and degrees awarded to women are presented in Table 1. Statistical significance is flagged with bold font.

Table 1. Summary of the data included in the analyses, including Spearman's rho correlation coefficients for each studied engineering discipline.

	Chemical (n=22)	Civil (n=20)	Electrical (n=20)	Mechanical (n=20)
Median free electives, % (range)	0 (0-12)	0 (0-14)	2 (0-19)	3 (0-12)
Median total choice, % (range)	34 (24-72)	51 (36-76)	53 (30-91)	37 (24-83)
Median % bachelor's to women (range)	32 (23-61)	28 (16-59)	14 (6-29)	15 (9-43)
% female enrollment, median (range)	33 (25-50)	36 (14-57)	15 (10-32)	16 (2-44)
Correl coeff % free electives v. F enrollment	$.154^{0.505}$	$.248^{0.291}$	$.396^{0.093}$	$\mathbf{.501^{0.018}}$
Correl coeff % free electives v. % F bachelor's	$.096^{0.679}$	$.248^{0.291}$	$.320^{0.182}$	$\mathbf{.445^{0.038}}$
Correl coeff choice v. % F enrollment	$.208^{0.366}$	$\mathbf{.530^{0.016}}$	$.284^{0.239}$	$.344^{0.117}$
Correl coeff choice v. % F bachelors's	$.272^{0.234}$	$.187^{0.430}$	$.349^{0.143}$	$\mathbf{.636^{0.001}}$

Note: Superscripts indicate p-values. Bold font indicates statistical significance.

Only mechanical engineering had a statistically significant correlation between free electives and female enrollment / degrees. The lack of significant correlations for chemical and civil engineering are not surprising, since the median free elective percentage in those disciplines was zero. Total choice correlated with female enrollment in civil engineering and bachelor's degrees for mechanical engineering.

Discussion

Numerous limitations were present in this study; for example, the programs included in the study make up only a small sampling of the engineering programs by discipline and nationwide. Additionally, the course choice opportunity data gathered from the institution catalogs characterize the degree programs at a single point in time; however, curricula can change over time. Some students matriculating through the degree programs (such as transfer students or those with Advanced Placement course credit) may experience curricular choice opportunity that is incongruent with what is reported in the catalog.

Keeping these limitations in mind and looking at the program correlations next to the median percentages of their bachelor's degrees earned by women, it is interesting to cautiously note that the correlations were the lowest (and not significant) for chemical and civil engineering, which—of the four disciplines—were more popular with women in terms of the national percentages of degrees awarded and at institutions in this data set. The correlations increased in value for electrical and mechanical engineering (the less popular disciplines with women, again in terms of the percentages of bachelor's degrees awarded); however, the correlations were only significant for mechanical engineering. These findings lead to the question as to whether curricular customizability or flexibility may matter more (i.e. hold more importance, value or appeal) to women in the disciplines less popular with women. Under very low women enrollment and low choice conditions, does the amount of curricular choice become more important? Is it just one more factor that can "tip the scales" for women more-so than for men? Clearly, the data in this preliminary study do not answer these questions nor provide any evidence regarding causations between undergraduate engineering programs' customizability and gender diversity; however, the results do yield more questions that the authors consider worth answering.

It is unclear whether (and the extent to which) students understand the variability in curricular choice between disciplines within institutions and across institutions as they enroll; qualitative information among environmental engineering students found that some discovered low choice within the first semester and found it as a potential detriment to staying in the major or detriment to transferring into the major.[21] Further study is needed to explore this awareness among students and if they identify choice as a factor in their enrollment and/or persistence in undergraduate engineering programs. For students considering leaving engineering or transferring among engineering majors, low choice may be perceived as just one more negative added to other unappealing factors such as a chilly climate in engineering, lower perceived social relevance of engineering, and/or countless other individual factors, perspectives, and experiences (Godfrey, 2007; Hartman and Hartman, 2006; Seymour and Hewitt, 1997).[4,7,22]

In a qualitative study that aimed to capture engineering disciplinary subcultures it was noted that, within the traditionally masculine culture of engineering education, disciplines vary in how welcoming they are of women's participation.[22] While chemical and materials engineering were found to have cultures that encompass both masculine and feminine characteristics (which is reflected in comparatively higher percentage women enrollment), the electrical engineering culture was the most masculine (again, reflected in comparatively low women enrollment).[22] Is it possible that in programs less popular with women, offering increased course choice opportunity in a given program is comparatively more correlated to the gender diversity in that program? If so, increasing the flexibility and/or customizability in engineering programs via free electives and other course choice opportunities might serve as a strategy to attract and keep more women engineering students.

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References

1.American Physical Society. Retrieved August 1, 2016. https://www.aps.org/programs/education/statistics/womenmajors.cfm

2.ASEE Engineering by the Numbers. American Society for Engineering Education. Retrieved August 23, 2015. https://www.asee.org/papers-and-publications/publications/14_11-47.pdf

3.Costentino de Cohen, C., Deterding, N. (2009). Widening the Net: National Estimates of Gender Disparities in Engineering. *Journal of Engineering Education, 98*(3), 211-226.

4.Hartman, H., & Hartman, M. (2006). Leaving Engineering: Lessons from Rowan University's College of Engineering. *Journal of Engineering Education, 95*(1), 49-61.

5.Lord, S., Brawner, C., Camacho, M., Layton, R., Long, R., Ohland, M., & Washburn, M. (2008). *Work in*

Progress: A Study to Investigate the Effect of Climate and Pedagogy on Persistence of Women in Undergraduate Engineering Programs. Proceedings, IEEE/ASEE Frontiers in Education Conference, Saratoga Springs, NY.

6.Ohland, M. W., Sheppard, S. D., Lichtenstein, G., Eris, O., Chachra, D., & Layton, R. A. (2008). Persistence, Engagement, and Migration in Engineering. *Journal of Engineering Education, 97*(3), 259-278.

7.Seymour, E., & Hewitt, N. M. *Talking about Leaving: Why Undergraduates Leave the Sciences*. Boulder, CO: Westview Press, 1977.

8.Forbes, M. H., Bielefeldt, A. R., & Sullivan, J. F. (June 2015). *The Choice Opportunity Disparity: Exploring Curricular Choice Opportunities for Engineering vs. Non-Engineering Majors*. Proceedings, ASEE Annual Conference & Exposition, Seattle, WA.

9.Forbes, M. H. (2015). *Course Choice Opportunity and Technical—Non-Technical Balance in Undergraduate Engineering Education. Doctoral.* Dissertation, University of Colorado Boulder.

10.Forbes, M. H., Bielefeldt, A. R., Sullivan, J. F., & Littlejohn, R.L. (2017). The Low Choice Culture in Undergraduate Engineering and Autonomy-Supportive Exceptions, *Journal of Professional Issues in Engineering Education and Practice,* Accepted; In-Press.

11.Robinson, K. J. (2011, September). The Rise of Choice in the US University and College: 1910–20051. In *Sociological forum* (Vol. 26, No. 3, pp. 601-622). Blackwell Publishing Ltd.

12.Deci, E. L., Vallerand, R. J., Pelletier, L. G., & Ryan, R. M. (1991). Motivation and Education: The Self-Determination Perspective. *Educational Psychologist*, *26*(3, 4), 325-346.

13.Ryan, R. M., & Deci, E. L. (2000). Self-Determination Theory and the Facilitation of Intrinsic Motivation, Social Development, and Well-Being. *American Psychologist*, *55*(1), 68-78.

14.Boggiano, A. K., Flink, C., Shields, A., Seelbach, A., & Barrett, M. (1993). Use of techniques promoting students' self-determination: Effects on students' analytic problem-solving skills. *Motivation and Emotion*, *17*(4), 319-336.

15.Kusurkar, R. A., Ten Cate, T. J., Vos, C. M. P., Westers, P., & Croiset, G. (2013). How Motivation Affects Academic Performance: A Structural Equation Modelling Analysis. *Advances in Health Sciences Education*, *18*(1), 57-69.

16.Mitchell, F., Gray, S., & Inchley, J. (2015). 'This choice thing really works…' Changes in experiences and engagement of adolescent girls in physical education classes, during a school-based physical activity programme. *Physical Education and Sport Pedagogy*, *20*(6), 593-611.

17.Massachusetts Institute of Technology. Retrieved July 29, 2016. http://meche.mit.edu/education/undergraduate/course-2a

18.U.S. News & World Report 2015-16. *U.S. News & World Report*, 2015. Engineering Rankings.

19.ASEE Engineering College Profiles. American Society for Engineering Education. Retrieved August 23, 2015. http://profiles.asee.org/

20.The Carnegie Classification of Institutions of Higher Learning. Indiana University, Bloomington, IN. Retrieved January 24, 2015. http://carnegieclassifications.iu.edu/

21.Bielefeldt, A. R., Forbes, M. H., & Sullivan, J. F. (June 2016), *Curricular Choice and Technical – Non-Technical Balance in Environmental Engineering Degree Programs.* Proceedings, ASEE Annual Conference & Exposition, New Orleans, LA. https://peer.asee.org/26622

22.Godfrey, E. (2007). Cultures within cultures: Welcoming or unwelcoming for women. In Proceedings of 2007 Annual Conference and Exposition of American Society for Engineering Education.