Mechanical Engineering Sustainability Curricular Content and Bachelor's Degrees Awarded to Women

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Abstract

Mechanical engineers can play an important role in contributing to a sustainable future. Groups traditionally underrepresented in engineering including women and minoritized groups are motivated to improve societal and environmental conditions. Thus, increasing the amount and visibility of sustainability-related content in mechanical engineering (ME) curricula and courses may broaden the demographics of students earning ME degrees. For example, mechanical engineering (ME) lags environmental engineering with respect to the percentage of Bachelor's degrees awarded to women in the U.S.; e.g., mechanical 17.3% versus environmental 57.8%. Potential correlations between the sustainability scores of a university under the American Association for Sustainability in Higher Education (AASHE) STARS rating system and the percentage of engineering Bachelor's degrees awarded to female students were explored. Courses with sustainability content were identified using information submitted by universities to the AASHE STARS program and/or course catalogs. This included Bachelor's level ME courses and general engineering courses required for ME students. The data set included 89 ME programs in the U.S. that were ABET accredited, of which 72 programs had AASHE STARS scores. There were weak statistically significant correlations between the total AASHE STARS scores and the percentage of engineering and ME Bachelor's degrees awarded to females. However, there was not a direct correlation between the percentage of females awarded ME Bachelor's degrees and the number of identified ME courses with sustainability. The demographics of students earning Bachelor's degrees in ME are likely due to a broad array of factors beyond the extent that sustainability is evident in the courses. For example, differences among private and public institutions were significant. Strong correlations were found between the number of mechanical engineering courses with sustainability and the percentage of Bachelor's degrees earned by females when relationships were explored within single states and either public or private institutions. This preliminary work suggests that sustainability may help attract and retain female students to mechanical engineering, sparking interest in future research.

Introduction

Mechanical engineers can play an important role in contributing to a sustainable future [1, 2]. Key concepts in sustainability include environmental impacts (over the cradle to grave lifecycle including greenhouse gas emissions, natural resource conservation, pollution minimization, energy issues), societal impacts (poverty alleviation, safety), and economics. Many institutions offer mechanical engineering elective courses (at the upper division undergraduate level and/or graduate level) with obvious ties to sustainability, such as renewable energy and wind power, while some institutions offer global / humanitarian engineering courses [3,4]. As a counterpoint to these elective options, there appears to be room to grow with respect to incorporating sustainability knowledge, skills, and attitudes within the required undergraduate courses taken by ME students [5,6].

One of the side benefits of increasing the amount and visibility of sustainability related content in mechanical engineering (ME) curricula and courses may be to broaden the demographics of students earning ME degrees. Mechanical engineering (ME) lags many other engineering disciplines with respect to the percentage of Bachelor's degrees in the U.S. awarded to women (engineering overall 24.1%, mechanical 17.5%, top discipline environmental 56.6% [7]). Previous research has identified stronger interest in sustainability issues, environmental protection, and social motivations among female students compared to male students. Therefore, visible sustainability in an ME program might attract female students and/or encountering sustainability issues in their ME courses could aid retention. The research question explored in this work was whether sustainability content in mechanical engineering courses within the curriculum might correlate with the percentage of females earning bachelor's degrees in ME across different institutions.

Background

ME lags engineering majors including civil, biomedical, and environmental in the percentage of Bachelor's degrees awarded to women in the U.S. (see Table 1). Environmental engineering has persistently graduated the highest percentage of female students. This may be due in part to the sustainability interests of female students. It is important to recognize that environmental engineering degrees are offered at fewer institutions than many other engineering disciplines. For example, the number of institutions in the U.S. with ABET Engineering Accreditation Commission (EAC) accredited degrees in environmental engineering is 82, compared to 358 in mechanical engineering [8]. Thus, students with strong environmental or sustainability interests may select from among the engineering majors available at a particular university.

Table 1. Percentage of U.S. Engineering Bachelor's Degrees Awarded to Females among total number of degrees in different disciplines [8-12]

Discipline (number U.S. institutions with ABET accredited Bachelor's)	2020-2021 % (n)	2015-2016 % (n)	2010-2011 % (n)	2005-2006 % (n)
All	24.0 (146,233)	20.8 (112,721)	18.4 (83,001)	19.3 (74,186)
Environmental (82)	57.8 (1,181)	45.6 (1,236)	44.3 (698)	44.2 (437)
Biomedical (116)	51.5 (8,165)	41.1 (6,177)	39.1 (4,066)	40.7 (2,917)
Chemical (158)	38.5 (9,872)	33.3 (9,864)	33.1 (6,487)	36.0 (4,452)
Civil (270)	28.1 (13,586)	24.0 (11,464)	21.0 (12,154)	22.0 (8,935)
Mechanical (358)	**17.3 (34,781)**	**13.8 (26,816)**	**11.7 (19,241)**	**13.1 (16,063)**
Aerospace (57)	15.9 (5,168)	14.3 (3,781)	13.4 (3,459)	18.5 (2,722)
Electrical (325)	15.5 (13,495)	12.7 (11,892)	11.5 (9,942)	14.2 (11,915)

ASEE Profiles / By The Numbers reports; 2023 ABET program search, Bachelor Degree, United States

The American Freshman study (HERI 2019-2022 [13-16]) has long documented the stronger environmental and social commitments and concerns of female over male students among incoming first year college students in the U.S.; data are shown in Table 2. Oberrauch et al. [17] summarized five different studies which indicated that women report stronger "environmental attitudes, concerns, and behaviors… than men"; their study found a gender gap with respect to sustainability attitudes that increased with age among first-year teacher training students.

Table 2. Data from the American Freshman Survey (HERI) [13-16]

Survey Item	Male				Female			
Year (n)	2022 (11,194)	2021 (14,701)	2020 (14,386)	2019 (39,646)	2022 (19,178)	2021 (22,968)	2020 (24,194)	2019 (55,859)
Students agree strongly or agree somewhat: The federal government is not doing enough to control environmental pollution	81.3	NA	NA	NA	89.8	NA	NA	NA
Students agree strongly or agree somewhat: Addressing global climate change should be a federal priority	NA	NA	82.6	82.2	NA	NA	89.3	88.7
Reason 'very important' in deciding to go to this particular college: This college's graduates make a difference in the world	32.7	36.7	35.7	28.6	42.9	46.4	45.3	37.6
Objectives considered to be 'essential' or 'very important'								
Helping others who are in difficulty	71.3	73.8	78.1	73.9	82.4	84.8	89.4	85.0
Becoming involved in programs to clean up the environment	31.4	33.0	37.5	39.4	37.8	40.5	45.9	49.2
Working to correct social inequalities	44.9	NA	NA	NA	63.5	NA	NA	NA

NA = not asked on the survey in that year

Within engineering, there is evidence that females are particularly interested in sustainability topics. Klotz et al. [18] found that female engineering students were significantly more interested than male engineering students in work in their careers related to disease, poverty and distribution of resources, and opportunities for women and minorities; female engineering students had lower interests in energy. Verdin et al. [19] found that community college students interested in engineering careers were motivated to address energy-related sustainability concerns; females were more interested in addressing social-related sustainability issues like disease, poverty, wealth distribution, and food availability compared to males. Further, Harrison and Klotz [20] found higher percentages of women in sustainability leadership positions (39%) than women in general engineering management positions (8%) and a higher representation of women among engineering faculty attending sustainability teaching workshops compared to the percentage of women among engineering faculty overall (32% vs. 12%).

Students from historically marginalized and underrepresented groups have sustainability, environmental, and social interests [21-23]. Interest in helping others is particularly strong among underrepresented minority (URM) students in STEM majors [21]. It is unclear if sustainability curricular content would be likely to increase the diversity of students earning undergraduate degrees in mechanical engineering. For example, the percentage of Bachelor's degrees awarded to URM students in engineering overall was 16.8% in 2021-2022, with a high of 22.7% in civil engineering, 18.1% in environmental engineering, and 17.3% in mechanical engineering [7].

Students with sustainability and engineering interests may choose to attend an institution that offers a degree that appears to align best with these interests. Historically, environmental was a common specialty area within civil engineering, with many departments named 'civil and

environmental engineering' (e.g., University of California Berkeley, Stanford, Georgia Tech, University of Michigan, MIT, University of Illinois Urbana-Champaign, Carnegie Mellon, University of Texas at Austin). Environmental activities in civil engineering typically focus on municipal systems, including drinking water, wastewater, and solid waste. At fewer institutions, environmental engineering is co-located with chemical engineering (e.g., Brown, University of Arizona, University of California Riverside, Yale). Here the environmental focus is often associated with chemical refining and industrial processes. Some institutions offer a 'general' engineering degree that includes extensive sustainability integration (e.g., James Madison University) or an environmental or sustainability-focused track (e.g., Olin, Baylor, Arizona State University, University of San Diego, Lafayette, Grand Valley State). In addition, there is a sustainable engineering concentration within civil engineering at Arizona State University and a renewable energy engineering degree offered at the Oregon Institute of Technology [24]. The air pollution and energy aspects of environmental engineering are often integrated into mechanical engineering. Some mechanical engineering programs offer concentrations or certificates in energy and sustainability or the environment, such as Boston University, Northwestern University, Arizona State University, and the University of Michigan Dearborn.

Students select a college based on a range of factors. It is unclear to what extent student interests in a specific major (e.g., which allows them to contribute to sustainable development) will outweigh other factors in their choice of an institution. For example, some students might constrain their choices to in-state public colleges on the basis of cost, or select a local college in order to live at home. Research has found that 70% to 80% of college students in the US attend college in their home state [25-26], but these percentages vary significantly based on the state and the race/ethnicity of the students. States with a low percentage of students who attend college out of state include Utah, Arizona, and California (only 8.4%, 11.9%, and 11.9% left the state), in contrast with New Hampshire and Minnesota where over half of the students left the state (52.9% and 51.3%) [26].

Studies have found that students typically have incomplete information when selecting a college [27], implying that students with sustainability interests may have difficulty accurately assessing this attribute of different colleges. Further, various factors are more important to female versus male students. A recent study found that women particularly consider feelings of fit, safety, and comfort [28]. Switching among different engineering majors is common among undergraduates [29-30]. In the study by Orr [31], about half of those who graduated in ME did not start in ME, and about 10 percent who started in ME graduated in another engineering major. Thus, students migrate among engineering disciplines, presumably as they become better informed and align their interests and capabilities with the requirements and future opportunities of the majors [32]. Hypothetically, a female student may initially elect to pursue mechanical engineering due to an interest in renewable energy and sustainability, but if she does not find this focus in her courses she might elect to change majors within engineering or leave engineering. Conversely, a female student with a strong interest in sustainable energy might initially opt to enroll in environmental engineering, but upon finding the program overly focused on water issues she might switch to mechanical engineering. Thus, sustainability content in mechanical engineering might serve to attract and/or retain female students.

Beyond sustainability integration into courses, higher education institutions can embrace sustainability through their operations. In a 2023 survey, 30% of students "selected sustainability as a top three factor when selecting a college" [33]. Thus, the overall sustainability reputation of an institution might attract students. In these cases, it might be particularly important to integrate sustainability topics into mechanical engineering courses in order to satisfy the sustainability interests of the students.

The research questions explored in this work are:

RQ1. Are there relationships between the demographics of students earning undergraduate degrees in mechanical engineering and institutional sustainability or sustainability content in the ME curriculum?

RQ2. Are there relationships between the percentage of female students earning degrees in engineering at an institution and the sustainability features of the institution as measured by AASHE STARS scores?

Methods

This study grew from a dataset developed for an earlier study on sustainability in mechanical engineering [3]. The selection criteria for including institutions in the study were previously described [3] and included programs graduating the largest number of ME undergraduates and top-ranked programs by the US News and World Report. This study focuses on higher education institutions in the U.S. with ABET EAC-accredited mechanical engineering programs, including 89 institutions overall.

Courses. The data on how many courses in mechanical engineering programs at various U.S. universities integrate sustainability topics were acquired from the preexisting dataset [3]. The earlier study counted the number of undergraduate mechanical engineering courses at the institution with sustainability content, based on data submitted by institutions toward earning a sustainability rating under the American Association of Sustainability in Higher Education (AASHE) Sustainability Tracking Assessment & Rating System (STARS) program [34] (79 programs) and course descriptions in the university catalog (10 programs). This identified both undergraduate courses in ME and general engineering courses required for ME students that included sustainability (termed MEs^{+} in this paper). We acknowledge that this information could be incomplete. Many catalog descriptions are very short, and for core courses may not mention sustainability if the integration is small or varies across different instructors. The total number of MEs^{+} courses at the 89 institutions in this data set ranged from 0 to 38 per institution (median 4, IQR 1-7).

Institutional sustainability. As a proxy for the sustainability of an institution, the ratings from AASHE based on its STARS scores were recorded. STARS is based on information self-reported by the institution and is freely available online [34]. The STARS ratings of the institutions in the data set were platinum (n=8), gold (n=29), silver (n=21), bronze (n=14), and reporter (n=7); 10 institutions did not participate in STARS. Reporter institutions do not have scores as they do not participate in the entire rating process. Thus, there were 72 institutions in the data set with

AASHE STARS scores. Three STARS scores were recorded: the total score, curriculum score, and academic score. The total score is a sum of five sub-scores: academics, operations, engagement, planning & administration, and innovation & leadership (which is an optional 'bonus' category). Operations has the highest weight in STARS overall, with the potential to earn 71 points. The academics category (maximum 58 points) includes both curriculum and research sub-categories. The curriculum sub-category includes 8 specific credits, where academic courses are weighted the heaviest at 14 of the 40 points. Institutional STARS ratings are valid for 3 years, so the ratings represent a range of years. In addition, some schools relied on older course data when they were renewing their ratings. Across the data set, the course information year ranged from 2016 to 2021, with a mode of 2019. Across the 72 institutions, the STARS total scores ranged from 26 to 89, curriculum scores from 12 to 40, and academic scores from 1.7 to 14 (medians 65, 26, and 8.6, respectively); see a box and whisker plot of the scores in Figure 1.

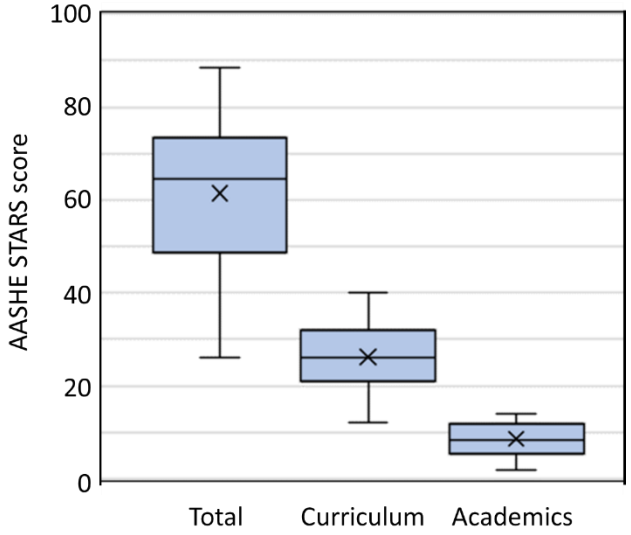

Figure 1. Range of AASHE STARS scores among the 72 institutions on the data set

Demographics. The demographics of mechanical engineering Bachelor's degrees awarded at each institution were obtained from College Factual [35]. The total number of ME Bachelor's degrees awarded and the percentage of those degrees awarded to female, Hispanic, and Black students were recorded. The demographics of the ME Bachelor's degrees in 2019-2020 at the 89 institutions in the data set are shown in Figure 2, disaggregated between private (n=33) and public (n=56) institutions. The percentage of females among the ME graduates was higher at private compared to public institutions (t-test $p < 0.001$). Next, for each of the 89 institutions, the total number of engineering Bachelor's degrees, the number of ME Bachelor's degrees, and the percentage of those degrees awarded to females in 2020-2021 were recorded [36]. Across the 89 institutions in the data set, the number of Bachelor's degrees awarded in engineering ranged from 17 to 2130 (median 380) and in mechanical engineering from 13 to 510 (median 132). The percentage of females among Bachelor's graduates in 2020-2021 in engineering ranged from 7.7% to 52.3% (median 25.8%) and in ME from 8.4% to 54.2% (median 18.7%). There was a higher percentage of females among the engineering and ME graduates at private compared to public institutions (t-test $p < 0.001$). These institutional differences are considered in later analyses.

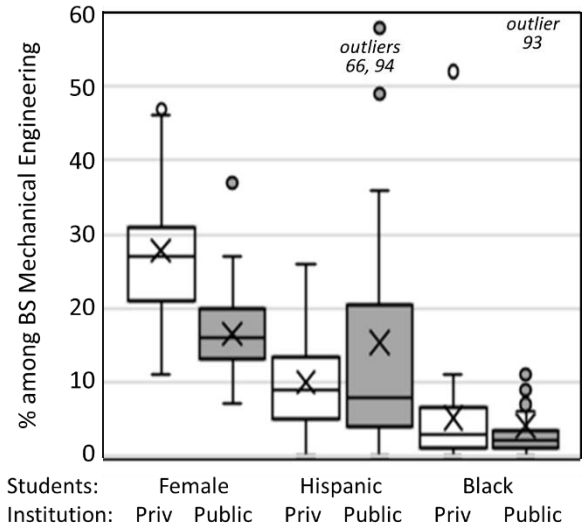

Figure 2. Demographics of mechanical engineering Bachelor's graduates in 2019-2020 among the 89 institutions in the dataset (33 private and 56 public)

Other Engineering Degrees. The other engineering degrees offered at the institution (beyond ME) were recorded in the order of most to least numerous degrees awarded (down to ~10 BS degrees) [36]. At the majority of the institutions in the data set, ME degrees were the most numerous compared to the other majors. Of particular interest was whether or not environmental and biomedical degrees were available at the institution, as these degrees have been shown to award a large percentage of degrees to female students, and competition from these degrees might lower the percentage of ME degrees awarded to female students. Institutions that offer ABET EAC-accredited Bachelor's degrees in Environmental Engineering were noted [8]. Among the 89 institutions in the dataset, 26 had ABET EAC-accredited Environmental Engineering programs.

Analysis. Initial correlation analyses with the 2019-2020 demographic data were conducted in Excel, calculating Pearson linear correlation coefficients. For correlation coefficients over 0.2, the significance p values were calculated. However, non-parametric statistics are appropriate for the course counts because they are non-normal and ordinal. The non-parametric Spearman's rank order correlation (rho, r_s) was used for the 2020-2021 data. The rules of thumb for interpreting correlation values are: less than 0.2 negligible, 0.2 to 0.4 weak, 0.4 to 0.6 moderate, and greater than 0.6 strong. Given the number of confounding factors, a p value of 0.10 was selected to indicate statistically significant findings and an attempt to balance Type 1 and Type 2 errors.

Limitations. The data set represents only a fraction of the total number of ABET EAC-accredited Bachelor's programs in mechanical engineering in the US (there are 358 and this dataset has 89). The majority of the institutions in the data set (72 of 89) show some commitment to sustainability by opting to participate in the AASHE STARS scoring process. The MEs$^+$ course counts are suspected to undercount the actual number of ME courses that integrate sustainability (see discussion in [3]). The demographics of those earning Bachelor's degrees may have been skewed by COVID. Further, there are inconsistencies in the timing of the AASHE ratings, course counts, and graduates. The data don't reflect students' processes of selecting institutions and persisting to graduation (e.g., students graduating in 2020-2021 likely were

selecting colleges in ~2016, but the information available and actual sustainability content in courses can vary over time).

Results and Discussion

The results of correlation tests with the 2019-2020 demographics of ME undergraduate degree recipients are shown in Table 3, across all institutions, public institutions, and private institutions. The dark tan color highlights correlations that meet the conventional statistical significance cutoff of $p<0.05$, while the light tan color highlights correlations with p values between 0.05 and 0.10. There was a weak positive correlation between the percentage of ME BS degrees awarded to females and the total number of ME$^+$ courses with sustainability. The correlations between female graduates with the AASHE STARS academic scores at all institutions and among the private institutions were also weak. At the private institutions, there were also weak positive correlations among the number of MEs$^+$ courses and percentage of BS degrees awarded to Hispanic students; the percentage of Hispanics among the ME graduates was also positively correlated with the AASHE STARS academic score at the private institutions. The weak negative correlation at public institutions between AASHE STARS total score and Hispanic ME graduates is unexpected. The potential weak positive correlations among the student demographics and total AASHE scores at the private institutions might reflect a combination of admissions and financial aid patterns, as well as student interests. The significant positive correlations among the AASHE STARS total, curriculum, and academic scores and the total ME$^+$ courses with sustainability are logical. Additional explorations focused on potential relationships among female students and sustainability.

Table 3. Correlation values among AASHE STARS scores, number of MEs$^+$ courses, and demographics of ME Bachelor's degree recipients in 2019-2020

Parameter	% female	% Hispanic	% Black	TS	CS	AS	SC
All institutions, n							
Total score (TS), 72	0.22$^+$	-0.17	0.05	1	0.91*	0.69*	0.44*
Curriculum score (CS), 72	0.19	-0.14	-0.01	0.91*	1	0.81*	0.42*
Academic score (AS), 72	0.34*	-0.07	0.02	0.69*	0.81*	1	0.48*
MEs$^+$ courses (SC), 89	0.25*	0.00	-0.07	0.44*	0.42*	0.48*	1
Public institutions, n							
Total score (TS), 45	0.18	-0.30*	-0.20	1	0.90*	0.72*	0.53*
Curriculum score (CS), 45	0.13	-0.26$^+$	-0.26$^+$	0.90*	1	0.80*	0.50*
Academic score (AS),45	0.14	-0.16	-0.22	0.72*	0.80*	1	0.52*
MEs$^+$ courses (SC), 56	0.12	-0.06	-0.10	0.53*	0.50*	0.52*	1
Private Institutions, n							
Total score (TS), 27	0.33$^+$	0.37$^+$	0.33$^+$	1	0.91*	0.64*	0.31
Curriculum score (CS), 27	0.29	0.28	0.25	0.91*	1	0.80*	0.29
Academic score (AS), 27	0.45*	0.44*	0.16	0.64*	0.80*	1	0.41*
MEs$^+$ courses (SC), 33	0.28	0.38*	-0.01	0.31*	0.29	0.41*	1

* $p<0.05$, $^+$ $p<0.10$

A deeper look at potential correlations between institutional sustainability and the percentage of Bachelor's degrees in engineering (ENG) and ME awarded to female students used the 2020-2021 data and non-parametric tests. Results are summarized in Table 4, where darker tan color highlights statistically significant correlations at standard statistical confidence levels ($p<0.05$) and light tan lower levels of statistical confidence (p between 0.05 and 0.10). There were weak

relationships between the STARS total score and the percentage of engineering and mechanical engineering BS degrees earned by female students. These correlations were the strongest among the private institutions. This may reflect that universities with strong sustainability commitments overall attract and retain more female students in engineering overall and ME specifically. (Note that there was a strong correlation between the percentage of females earning BS degrees in engineering and ME, r_s 0.735.)

Table 4. Spearman correlations among percentage of females earning Engineering (ENG) and ME Bachelor's degrees and the AASHE STARS scores or number of MEs$^+$ courses, 2020-21 degree data

Parameter	ENG % female	ME % female
All institutions, n		
Total score (TS), 72	0.296*	0.263*
Curriculum score (CS), 72	0.179	0.222$^+$
Academic score (AS), 72	0.190	0.309*
MEs$^+$ courses (SC), 89	0.215*	0.143
Public institutions, n		
Total score (TS), 45	0.335*	0.194
Curriculum score (CS), 45	0.223	0.136
Academic score (AS),45	0.108	0.121
MEs$^+$ courses (SC), 56	0.245	0.054
Private Institutions, n		
Total score (TS), 27	0.416*	0.400*
Curriculum score (CS), 27	0.256	0.309
Academic score (AS), 27	0.203	0.421*
MEs$^+$ courses (SC), 33	0.054	0.044

* $p < 0.05$, $^+$ $p < 0.10$

Across all institutions, the strongest relationship with the percentage of females earning ME degrees was a weak correlation with the STARS academic score. The correlation is interesting given that the academic score represents all courses at the institution, while there was not a statistically relevant relationship found between the MEs$^+$ course counts and the percentage of ME BS degrees earned by female students (Table 4). The relationship between the academic score and degrees awarded to female students in ME might reflect the ease with which sustainability-motivated students can find sustainability-related electives if they choose to do so. Clearly, there are a number of factors that influence the percentage of females among Bachelor's graduates in engineering and ME, but there are indications that sustainability might be among those factors.

Six sub-sets of the data from states with three or more private or public institutions were explored. This reflects the fact that the majority of students attend college in-state [26] and may therefore be comparing among institutions in their home state. Results are shown in Figure 3. Private institutions in two of the three states (Massachusetts and Pennsylvania) show a correlation between the percentage of ME BS degrees earned by female students and the number of ME$^+$ courses with sustainability (Pearson correlation 0.9996 and 0.8498, respectively). One of the private universities in California, a private religiously affiliated institution, had an unusually high number of courses (21) compared to the others (0 to 4). Without this outlier, the correlation was 0.8057 among the other four private institutions in California. Among the public institutions,

there was a strong correlation in Alabama (0.8976) and moderate correlations in Texas (0.5246) and California (0.4286). In general, the state-level analysis shows trends toward higher percentages of BS degrees in mechanical engineering awarded to females when the institution had a higher number of ME^{+} courses that included sustainability topics.

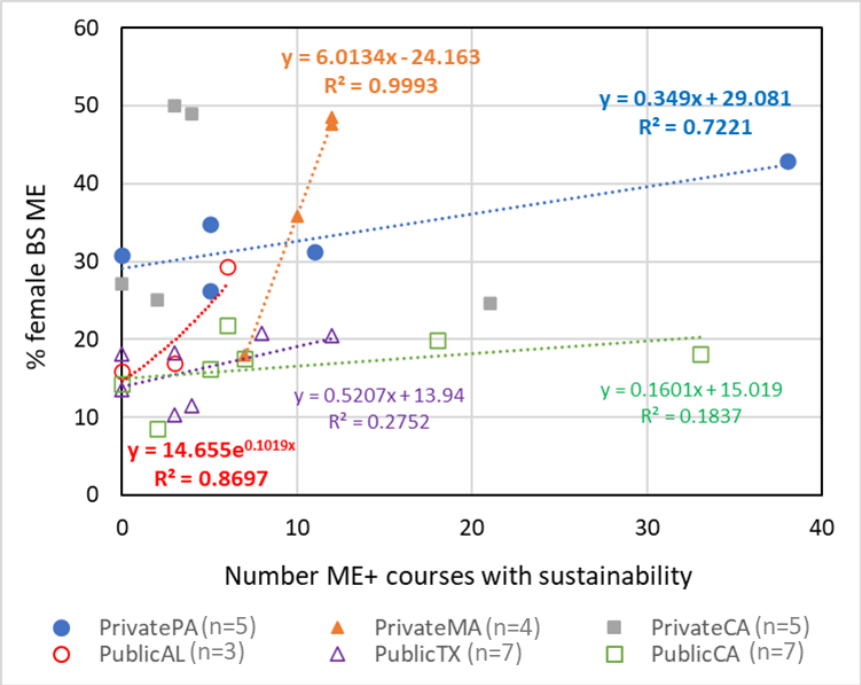

Figure 3. Percentage of ME Bachelor's degrees awarded to females (2020-21) versus the number of ME^{+} courses at the institution with sustainability; data sets within states and either private or public institutions

The anticipated concern that having an ABET-accredited environmental engineering (EnvE) bachelor's degree at the institution would lower the female enrollment in ME was not found (Table 5). The opposite trend was found at public institutions. Perhaps having an EnvE degree available attracted more female students to engineering at the institution, and once there female students migrated to ME.

Table 5. Average percentage of Engineering (ENG) and Mechanical Engineering (ME) Bachelor's degrees awarded to female students (2020-21)

Institution Type	All institutions		Private institutions		Public institutions	
	ENG	ME	ENG	ME	ENG	ME
Institution without EnvE	27.0±9.6	20.5±10.3	33.6±10.8	28.7±11.8	21.7±4.6	16.2±4.8
Institution with EnvE	29.0±7.0^{+}	22.7±7.5	35.0±8.7	27.0±10.3	26.4±4.0*	18.4±3.8^{+}

*T-test with EnvE versus without EnvE (excluding 3 institutions with non-ABET EnvE at private institutions and 2 with non-ABET EnvE at public institutions), * $p < 0.05$, $^{+}$ $p < 0.10$*

Future Work

The results indicate that additional studies are warranted. Firstly, correlation should not be misinterpreted as causation. It is unclear if female students in engineering were motivated to select an institution partially based on its sustainability commitment broadly and/or the

availability of courses related to sustainability. A possible alternative explanation is that institutions with a greater commitment to sustainability have different admissions or financial aid policies that result in admitting more diverse students into engineering and/or systems to support these students to successful graduation. Research could be conducted to ask female students if the sustainability of the institution overall and/or the courses available impacted their college selection decision. The demographics of students enrolled in ME elective courses with strongly visible sustainability, such as Renewable Energy, Sustainable Energy, and Global Development courses, could provide evidence of female student interest in sustainability topics within ME. Surveys or interviews with female students, in particular those transferring into or out of ME, could ask directly about the potential role of course content related to sustainability in their decision. Large quantitative studies could use multi-level modeling to attempt to account for the broad array of factors that influence where undergraduate students attend college and their eventual graduation in mechanical engineering.

Summary and Conclusions

The quantitative research found some weak correlations between sustainability at an institution based on their overall AASHE STARS scores and the percentage of engineering and ME Bachelor's degrees earned by females. This correlation could be due to female students being particularly attracted to sustainability and embracing it through their choice of institution and/or engineering major. There were not significant correlations between the number of ME^{+} courses with sustainability that were identified and the percentage of the Bachelor's degrees awarded to females. This is likely due to confounding across the data set by other important factors. Across public or private institutions within single states, there is some evidence that institutions offering a higher number of ME^{+} courses with sustainability awarded a higher percentage of the ME Bachelor's degrees to female students.

If institutions offer sustainability-focused elective courses, it is important that students are given sufficient flexibility in their curriculum to take these courses, via technical electives, humanities/social science electives, and/or free electives. Previous research found fairly low curricular flexibility in ME at many institutions which may constrain students from selecting courses that match their interests [37].

A key issue in translating the findings to practice is to ensure that sustainability is integrated into courses in the ME curriculum and that this integration is externally obvious. Sustainability topics can be integrated into any course, and there are many examples and models of successful integration into ME courses. The addition of even a couple of words into course descriptions in the catalog (e.g., sustainability, environmental impacts, social factors) could draw attention to this important topic. This is particularly relevant for required courses such as thermodynamics, materials, and manufacturing. Institutions might alternatively offer a number of elective courses with a strong sustainability focus, such as renewable energy and/or sustainable development. These courses could form a concentration within mechanical engineering. Making sustainability commitments readily apparent on the ME program website could help attract prospective students, including women and underrepresented minorities. Encountering genuine sustainability-related content in their courses could help motivate and retain these students.

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