How Does Enrollment Management Affect Student Population Diversity in Biomedical Engineering?

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Introduction:

The number of Bachelor's degrees awarded in Biomedical Engineering has almost doubled between 2009 and 2018 [1]. With this increased growth, the resources of many Biomedical Engineering departments are not enough to satisfy the increasing demand for admission and enrollment. Therefore, many programs apply rigorous enrollment management protocols (EMPs) to presumably ensure the academic suitability of candidates. Some EMPs are applied even after admission to an institution or degree program. Common EMP include GPA thresholds, essays, other application materials and the use of "weed-out" courses. The intention of these practices is to select for only academically prepared and highly committed students. However some evidence suggests the weed-out tradition selects against students on a full spectrum of talent and academic preparedness [2], [3]. In addition, there is evidence that women and under-represented minorities (URM) are affected negatively by this approach [2].

In addition to the explicit exclusion factors, such as those implemented in EMPs, implicit exclusion factors have been an area of study. Over the last few decades, there has been a lot of research regarding characterizing and investigating the "leaky pipeline" in STEM fields [4], [5]. The leaky pipeline describes the phenomenon seen in many STEM fields, that show women and URM become less and less represented in later stages of academia, from high school, college, grad school, post-docs, and finally independent research investigators. Implicit exclusion factors, such as departmental culture, a lack of a sense of belonging, perceptions about work and life balance, may be contributing factors to this leaky pipeline in STEM.

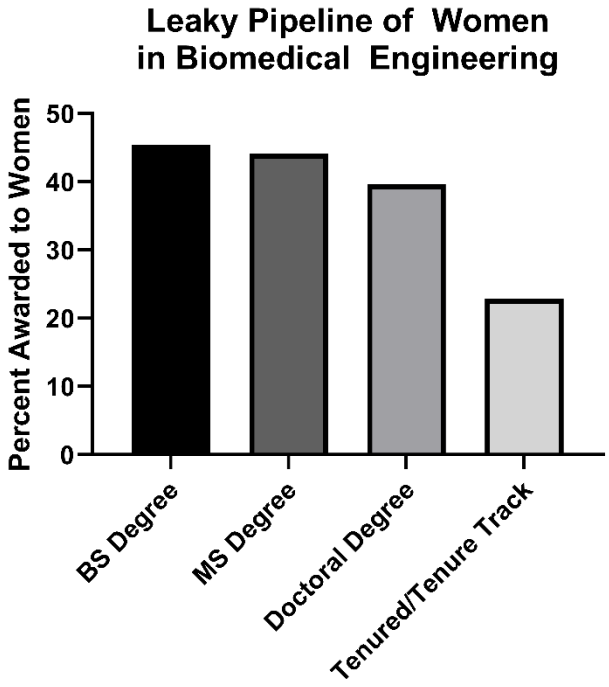

Figure 1: Fewer women move on to higher stages of academia. Modified from data in the 2019 *Engineering by the Numbers*.

There are fewer studies that look at the effects of explicit and implicit exclusion factors specifically in biomedical engineering. From a recent annual report that ASEE publishes [1], we see the leaky pipeline of women when looking at the percentage of degrees awarded to women and the percentage of Tenure/Tenure-Track faculty positions in BME (Figure 1). The same data are not made available for URM at all academic stages.

Many programs are created to increase and broaden representation of women and URM in STEM fields by recruitment and outreach. The goal of these programs is to increase the inlet of the pipeline to STEM field (e.g., increase diversity at admission). These programs address the "inlet" of the leaky pipeline, by increasing the number of people interested in the field. These programs are quite important in addressing the initial diversity of students but may not necessarily address retention in enrollment. However, as noted in Figure 1, women are relatively well represented in BME undergrad, especially compared to other engineering majors. As observed in this study, the inlet of women in the pipeline is not the alarming data. Rather the issue identified here is the leakiness of the pipeline. That is, the issue is really a question of persistence and retention within the field. Here we collect data related to the retention of students, specifically women and URM in BME between freshman and later years.

This study looks at data from a biomedical engineering program in a large public R1 university, with a student body of about 20,000 students, ~4,000 of which are in Engineering. At the institution where this study is performed, the admissions department determines who is admitted to the BME program. In effort to manage enrollment, the BME program requires a grade of a B or better in five different math and science courses as a pre-requisite to enroll in a fall semester sophomore year gateway course in the BME major. A crucial question is whether or not this specific EMP may select against women and other URM, similar to the weed-out tradition. The aim of this study is therefore to understand the potential negative effects of this particular EMP on women and URM. The results of this study are a first step in characterizing demographics and diversity, which will serve as a baseline for future studies.

There is growing evidence and research showing the importance of diversity in improving the quality of education and research. For example, in a multi-institutional longitudinal study performed with 11,680 students attending four-year institutions in the US found that racial diversity has a positive effect on educational outcomes[6]. In another multi-institutional study, evidence supported the idea that prolonged contact with racially diverse groups has stronger effects on complex thinking of individuals, compared to those with more limited contact [7]. The positive effect of diversity manifests though all levels of academia. For instance, research articles from gender heterogeneous groups receive a higher number of citations compared to single gender teams [8].

However, there is still not enough research on diversity in the biomedical workforce at the undergraduate level, and even less data is specific to biomedical engineering. We believe that such research is critical to understanding a major potential source of the lack of diversity and to begin to address the problem. As Tell Whitney, a leader in the tech field puts it "Diversity drives innovation. When we limit who can contribute, we in turn limit what problems we can solve".

Materials and Methods:

Data Collection

Enrollment of students (n=415) who initially declared BME were tracked over two academic years, including fall enrollment data from 2018 and 2019. Data were collected, with IRB approval (IRB#11614). To protect student privacy, identifying data variables were recoded or removed. Data variables include a recoded ID, major degree, minor degree, term of admission, current GPA, high school GPA, ACT scores, SAT scores, gender codes, IPEDS (Integrated Postsecondary Education Data System), race/ethnicity data, and citizenship.

Analysis and tabulation of data was performed in R (R Core Team, 2019) to track and compare lists of student IDs from year to year, categorize student variables, and tabulate demographic data. Student enrollment was tracked by comparing lists of recoded (deidentified) IDs of students from year to year and comparing them to lists of freshmen (or transfers new to the major) and graduates.

Categorization of Under-Represented Minorities

URMs self-identified as "Hispanic", "Alaskan Native or American Indian", and "Black or African American" as designated by a student's IPEDS according to enrollment data provided by the institution. Multi-Race students were classified as URM if one of their documented races is among those previously mentioned URM groups. International students and students who prefer not to disclose race were not classified as URM.

New Major Classification

Of those students that subsequently switched from BME to another major, the new major was recorded and classified as: 1) a different engineering degree; 2) a Science, Technology, or Math (STM) degree; or 3) a non-STEM degree. Examples of majors in these categorizations are listed in Table 1.

Table 1: Categorization of Majors

Non-STEM Majors	Other Science, Tech, Math	Other Engineering
Art	Anthropology	Chemical Engineering
Business	Biochemistry	Civil Engineering
Human Resources	Biology	Computer Science
Journalism	Health and Exercise Science	Engineering Physics
Public and Non-Profit Administration	Math	Industrial Systems Engineering
Undeclared	Microbiology	Mechanical Engineering
	Physics	Petroleum Engineering
	Psychology	
	Sociology Criminology	

Statistics and Data Reporting

In order to reduce the potential for deductive reidentification of individuals, we do not report identifying features of groups of individuals less than n=8. Unfortunately, this limits our ability to present more intersectionality of the data (e.g., the breakdown of persistence of Black/African American women, or Native American men). This is done in order to protect the identity of students in the study.

Differences between groups were analyzed in GraphPad Prism version 8.3.0, GraphPad Software, La Jolla California USA, www.graphpad.com. Unpaired two-tailed t-tests, with an alpha=0.05 were used to determine statistical significance between two groups (e.g., Switchers vs. non-Switchers). Two-way ANOVA, followed by Tukey's multiple comparisons, was used to determine differences of High School GPA between Switchers and Non-Switchers and with regard to gender.

Results and Discussion:

Overall Demographics of Study Population

Over the 2018-2019 study period, women made up 55% (n=230) of the entire study population of enrolled undergraduate students in BME (Table 2). As a comparison, across the United States, women make up 26.3% of enrolled students in any engineering degree in the Fall of 2018 [1]. We are not aware of the percentage of women enrolled in Biomedical engineering programs, but Biomedical Engineering typically awards a relatively higher proportion of degrees to women compared to other engineering fields. As a comparison, 45.4% of Bachelor's degrees in Biomedical Engineering were awarded to women in 2018 (Figure 1), and 21.9% of Bachelor's degrees in all engineering fields were awarded to women [1].

Table 2: Breakdown of numbers of students in study.

	All	Women	URM
<1 Academic Year	50	30	15
Switchers	174	101	55
Non-Switchers	191	99	34
Total	415	230	104

The 55% number of women seems encouraging, because it is above average compared to other engineering majors and because it is above equality. Relative to the leaky pipeline issue, it appears that this BME program has a relatively strong inlet for women. *These data indicate the need to focus on retention and climate issues rather than just recruitment.*

URM made up 25% (n=104) of the total study population (Table 2). Nationwide, 8.5% of enrolled undergraduates in any engineering degree are Hispanic, 4.3% are Black or African American, and less than 0.3% are American Indian for a total of ~13% URM [1]. Again, these URM numbers in BME are encouraging because they are above the average for engineering overall, but are still under-represented relative to the nationwide general population demographics.

Diversity and Retention of Students

While the previous data describe the overall demographics of admitted students, this study is interested in the retention of these students. The overall study population includes freshman and transfer students, a group in which persistence cannot be measured yet, until we gather future data. While the overall student population in the study includes 415 students, current freshman have not established their persistence in the major yet. Looking at the subset of students that have been around at least one academic year, (n=365), we analyze how many have switched or persisted. In this study, we observed striking results related with student demographics changes between first and second year. Between the first year and the sophomore-level gateway course, approximately 48% of students (n=174) switched major ("Switchers") or left the university.

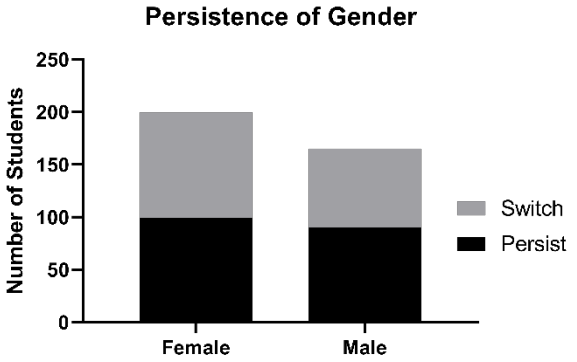

Figure 2: Persistence of Male and Female students in BME program. More females switched out of BME than males.

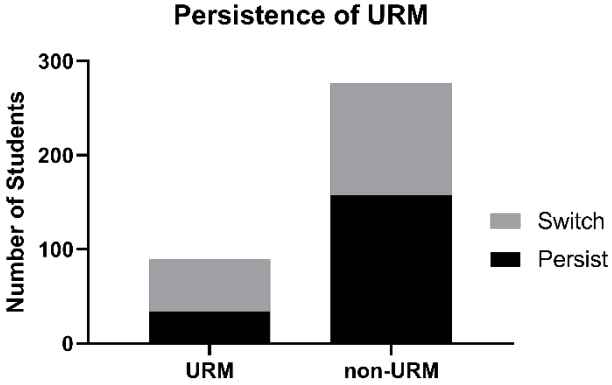

Figure 3: Persistence of URM and non-URM students in BME program. Switchers are disproportionately URM.

Switchers were slightly more likely to be female (Figure 2, 57% of Switchers are female, compared to 52% Non-Switchers). Out of the 200 female students, about half of them (n=101) switched majors (compared to the 45% of males that switched).

Switchers were also disproportionately URM (Figure 3, 32% of Switchers are URM, compared to 18% of Non-Switchers). Another way to look at this number is that out of n=89 URM students, n=55 (62%) switched major.

Most, 75%, of the switchers left engineering entirely, and of those, most switched into a STM major such as those listed in Table 1.

These data, showing drastic changes in demographics between first and second year demographics, highlighting the importance of freshman engagement. Some evidence supports

the idea that specialized freshman courses help to retain students, especially when they are major specific [9]. At the institution where this study occurs, there is a freshman course for all engineering, but not specifically for the BME major. This could be one potential way to increase overall retention by engaging with the department and creating a sense of belonging. Although, it is unclear how this could affect retention of URMs and women.

Factors Related to Academic Preparedness

Of the 63 students who switched out of the major in the 2018 cohort, a little over half (n=37) did not meet the B or better grade requirements in the EMP. One third (n=21) did meet all of the grade and course requirements. Another 6 students met the grade requirements but did not attempt one of the five required classes. Of the Switchers that met all the requirements, they were disproportionately female (n=16), that is ~76% of the group. Almost all of the Switchers that met all of the requirements, switched into another major that was STM, except for a couple that switched into another engineering major. Speculating, it is possible that some of the high achieving students are leaving for another typical pre-med major, which may be perceived as "easier" than BME. They may also be leaving due to attitudes about perceived career prospects of BME majors relative to other STEM majors, documented by others [10], [11]. Clearly, there is a necessity to investigate the non-grade related reasons of these students leaving BME.

In attempt to understand how high school academic preparedness may influence or predict retention in the major, we looked at high school GPA and standardized test scores including SAT and ACT scores (Figure 4). Comparing high school GPA of Switchers vs Non-Switchers, Switchers had a statistically lower GPA (3.70 ± 0.3, p=0.009) compared to Non-Switchers (3.80 ± 0.2). After findings that women that left STEM at one institution, had higher average grades than both men that switched or persisted [12], we compared the average high school GPA of female students who switched vs men who switched (Figure 4). Females in general had significantly higher GPAs than males. We found that the female Switchers had a significantly higher high school GPA (3.77 ± 0.2, p=0.018) than male Switchers (3.59 ± 0.4). Interestingly, male Non-Switchers, did not have a significantly higher GPA than female Switchers (p=0.88). This may be related to the observation that many women feel they must work harder than men to achieve the same level of success, which stems from stricter performance measures applied to women vs men in many facets of life and work [13]

When looking at standardized test scores, the averages of Non-Switchers were higher for both the SAT and the ACT (Figure 4). However, the ACT was the only one with a significantly different score (28.4 ± 4 vs 30 ± 3, p=0.03), SAT differences did not reach statistical significance (1327 ±130 vs 1354 ±120, p=0.5). It should be noted that not all students took both the SAT and the ACT. Use of standardized test scores to for admissions has been controversial in recent years, since it has been shown to potentially be racially biased [14] and do not necessarily contribute to predictors of persistence [15].

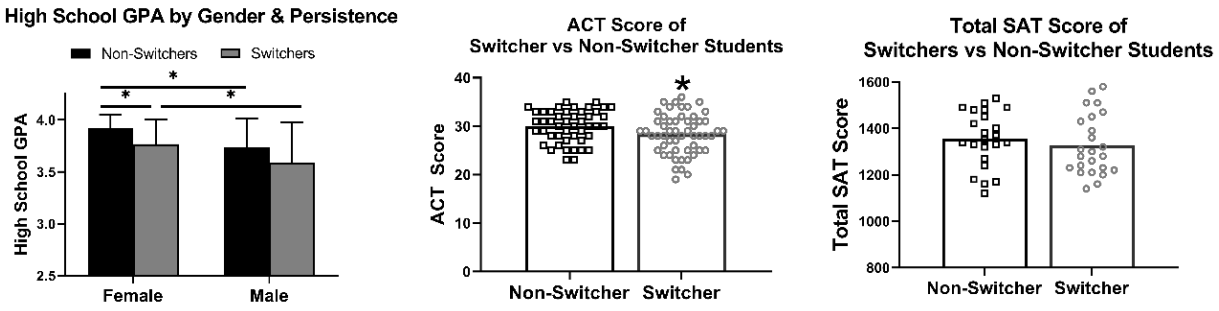

Figure 4: Academic preparedness of students who switched major. * indicates $p < 0.05$ between groups.

Conclusions and Future Work

Identification of reasons for leaving the major can be informed by these results. A qualitative study, involving interviews with students, to identify factors that contribute to persistence or switching is of interest to this work. A number of potential factors could contribute to persistence of all or specific groups of students. For instance, the study institution has an office specific to engineering to increase diversity and inclusion by providing resources for tutoring, scholarships, mentorship, and professional development opportunities. Interviews with students who leave the major could help identify whether or not these students identified these resources and took advantage of them or not.

Besides academic preparedness and explicit exclusion of students from the major due to academic performance, there could implicit exclusion factors causing loss of students. Academic climate and a lack of a sense of belonging are examples of such implicit exclusion factors. Interviews with students who have left or stayed could help to identify departmental culture factors that may be supporting or dissuading students. A number of factors have been identified in other STEM fields, such as the quality of teaching, grading practices, inadequate advising, lack of peer study group support, competitive culture, problems related to class size, and time to degree [16]. These factors may affect certain groups in different ways. For example, compared to white students, URM were more likely to cite the following reasons for switching: "inadequate high school preparation, a difficult transition to college, the competitive, unsupportive STEM culture makes it difficult to belong, and discouragement/loss of confidence due to low grades in early years" [16]. Women were more likely to cite a loss of interest or motivation to pursue a STEM major [16].

There are some strategies available to address some of the factors that lead to retention of students. Due to the fact that the biggest changes in academics happen between freshman and sophomore year, strategies should be implemented during the first year of college. An increase sense of belonging may be affected by specialized freshman courses [9] which provide a chance to engage in the student's intended major immediately. "Inadequate advising" could be addressed by engaging freshman early on to identify an appropriate major, discuss career prospects for BME, and strategies for professional development. In this study institutions, BME

students are not advised by BME faculty until their freshman year. Engaging freshman with department specific advising could be an opportunity for improvement.

The results of this study serve as the first step to understand and characterize the demographics of the students in the BME program at a single institution. At this moment, data related to other engineering programs in this institution are not available for publication. However, an investigation of retention and demographics relative to other engineering majors, with and without EMPs would provide an important perspective for interpreting this data. We also hope that other biomedical engineering programs will follow suit, and report back, to help provide a better picture of the state of the field nationwide in a range of institutions. Future work to characterize different EMPs at other BME departments and identify best practices and practical solutions is necessary to help retain women and URM in BME.

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