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A NEW LOOK AT THE INSTITUTIONAL IMPACT ON WOMEN IN POSTSECONDARY ENGINEERING EDUCATION 1966–2007

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Postsecondary studies of women in the engineering disciplines tend to treat the issues of recruitment, retention, and density of female students as an overarching metric that affects all institutions equally. Samples of doctoral-granting institutions are often used as proxies to make projections regarding the field as a whole, and it is assumed that institutional gender segregation is largely an issue of the past. This study uses 40 years of US Department of Education data to explore how an institution's Carnegie classification impacts several characteristics of its degree conferral behavior and reveals some surprising findings, such as only one half of all physics programs on average over the past 20 years awarding to women each year. Masters colleges are found to play an important role in the education of female students in certain majors, and institutional types and majors are found to be strongly stratified nationally based on their conferral patterns to women.

KEY WORDS: *IPEDS, HEGIS, engineering, postsecondary, institutional impact, degree conferral trends*

1. INTRODUCTION

The lack of gender diversity in postsecondary engineering education has attracted significant attention over the past decades. The National Engineering Education Delivery System, in collaboration with the Association for Computing Machinery's Committee on Women in Computing, has indexed nearly 900 articles since 1980 on the subject of women and computing alone (*NEEDS*, online). A search of Google Scholar turns up more than 95,000 works containing the terms gender and engineering. Yet, while the broader gender gap in college education has closed and women now outnumber men in the ranks of the college-educated (Goldin et al., 2006), women still lag significantly behind in engineering. Beginning with its 2000 report, the National Science Foundation reported that women for the first time accounted for more than half of all students in the fields of science, technology, engineering, and mathematics (STEM), a trend which has held for the last 7 years (*S & E*, 2008). However, STEM includes fields with historically higher percentages of women, such as the social sciences. When restricting to engineering disciplines, the picture is far less rosy, with women accounting for just 20% of all graduates in 2007 (Figs. 1 and 2).

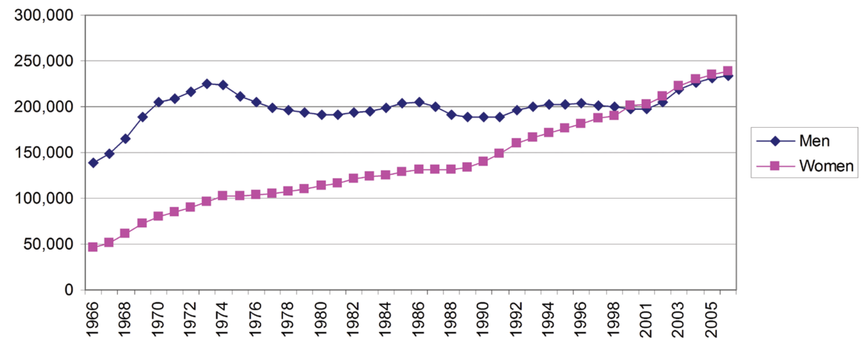

FIG. 1: Total number of baccalaureate degrees awarded annually in STEM fields 1966–2007 (NSF)

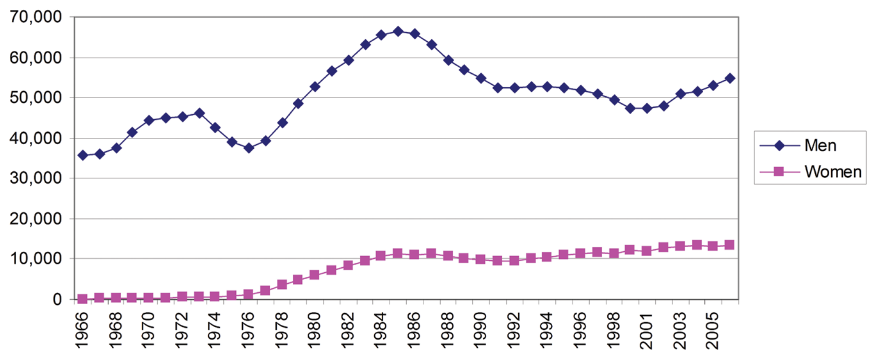

FIG. 2: Total number of baccalaureate degrees awarded annually in engineering fields 1966–2007 (NSF)

The question of *why* women constitute such a low percentage of engineering graduates has attracted a significant volume of literature over the years. Persistence and engagement studies have found that engineering students are not substantially different from those in other majors and that there are no signature characteristics that distinguish those that transfer out of engineering (Ohland et al., 2008; Seymour & Hewitt, 1997). Many factors have been identified as contributing to the so-called "leaky pipeline" (National Academy of Sciences, 2006), such as the competitiveness of classroom culture, gender role expectations, different learning styles, and K-12 experiences "deselecting" women's interest in STEM fields (Seymour, 1995). Some institutions have found success in increasing the volume of women in their programs, such as Carnegie Mellon's school of computer science (Margolis & Fisher, 2002), but thus far these have not been replicable on a national scale.STEM education is often treated as if degrees are awarded by a uniform fabric of institutions. Studies rely on proxy datasets based on a sample of institutions that are clustered by geography or type. For example, a recent study on retention (Ohland et al., 2008) relies on the MIDFIELD database, which includes only doctoral-granting universities. The author's caveat this means their findings "may be representative of…students at larger research institutions, [but] they are not representative of the diversity of institutions in the United States," (p. 266) while one of their tables (p. 265) reinforces this by finding that a majority of computer science degrees come not from the doctoral institutions they are studying but from masters colleges. Papers that have explored institutional-type differences in gender densities have largely focused on explanations of disciplinary composition (Jacobs, 1999) rather than differences within a single major across institutions.

2. IPEDS AND HEGIS SURVEYS

All national longitudinal studies of postsecondary degree conferrals in the United States rely on the Integrated Postsecondary Education Data System (IPEDS) and Higher Education General Information Survey (HEGIS) datasets produced by the United States Department of Education. These surveys cover all degrees awarded in the country from 1966 to present and offer a taxonomy grouping degrees by discipline (the current taxonomy is known as CIP2000). IPEDS data back to 1987 is available from the Department of Education's website, but earlier years using the HEGIS survey are currently available only in archival format. Most studies of longitudinal degree conferrals therefore rely on an aggregated compilation of HEGIS and IPEDS produced by the National Science Foundation (NSF) and made available through its WebCASPAR service. NSF itself issues a summary report of degree conferral patterns in STEM disciplines every few years, the most recent covering 1966–2006, released in October 2008 (*S&E*, 2008). Portfolios of degree lines are grouped together in order to capture the entirety of each field; however, in some cases the specific groupings used by NSF may bias findings derived from it. For example, Table 1 shows how the NSF groups instructional lines under the heading *Computer Sciences*.

Since it was introduced in 2000, the CIP2000 instructional line 11.0801 (web page design) has been awarded 2583 times at the baccalaureate level, of which 912, or 35% were women. Examining the Carnegie 2000 classification of institutions awarding this degree (the Carnegie classification is a method of grouping institutions by research extent and primary degree types awarded), the top two institutional types are schools of art, music, and design and associates colleges (schools at that designation level primarily award associates degrees, but may also award a certain number of baccalaureate degrees each year.) Over this period, only 12 degrees in this class have been awarded by research extensive institutions. In addition, the line 11.0501 (computer systems analyst) is crosswalked by IPEDS to 52.1203 (business systems analysis & design), and 11.0901 (computer networking) is crosswalked to 52.1204 (business networking), suggesting a strong focus on application rather than in-depth theory instruction.

Some subdisciplines of computer science have significant representation of women, such as web page design, but these are highly specialized degrees, and in the core theory areas of computer science, women make up only 18 to 23%. The definition for line 11.0101 is "a general program that focuses on computing, computer science, and

TABLE 1: The NSF groups the following instructional lines under the heading *Computer Sciences*

CIP2000 Code	Title	Total BS since 2000	% Women
11.01	Computer/information sciences, general	170,353	23.01
11.02	Computer programming	5546	23.40
11.03	Data processing technology/technician	1929	29.13
11.04	Information sciences/systems	54,551	33.13
11.05	Computer systems analysis	8988	28.09
11.07	Computer science	67,679	18.43
11.08	Web page design, computer graphics, database management	6342	31.07
11.09	Computer systems networking and telecommunications	15,542	20.81
11.10	System administration, networking, management	6032	22.04
11.99	Computer/information sciences, other	12,471	32.41

information science and systems as part of a broad and/or interdisciplinary program," while 11.0701 is "a general program that focuses on computers, computing problems and solutions, and the design of computer systems and user interfaces from a scientific perspective [including] instruction in the principles of computational science, and computing theory." Both of these are reasonable definitions of a theory-driven course of instruction in computer science and so are used as the definition of computer science for this study, while the others are dropped.

In addition, NSF separates only a small number of engineering majors into their own entities in its data, lumping majors such as agricultural engineering, bioengineering, industrial engineering, and nuclear engineering under the heading "other engineering". This prevents these smaller majors from being studied independently to examine trends between larger and smaller disciplines. NSF data also does not allow degree conferrals to be subdivided by Carnegie classification, only by a coarse breakdown of highest degree offered. For the purposes of this study, therefore, a special unified compilation of HEGIS and IPEDS data available at the University of Illinois was used to track graduation trends, rather than the NSF WebCASPAR data.

3. INSTITUTIONAL DIFFERENCES

Ohland et al. (2008) note that individual institutions can exhibit very different environments for their students. Most existing studies (including their own), however, look either at a small sample of institutions (traditionally doctoral-granting ones) or treat the universe of engineering degrees as uniform, abstracted from their institutional underpinnings. Jacobs (1999) studied institutional differences in the density of female students

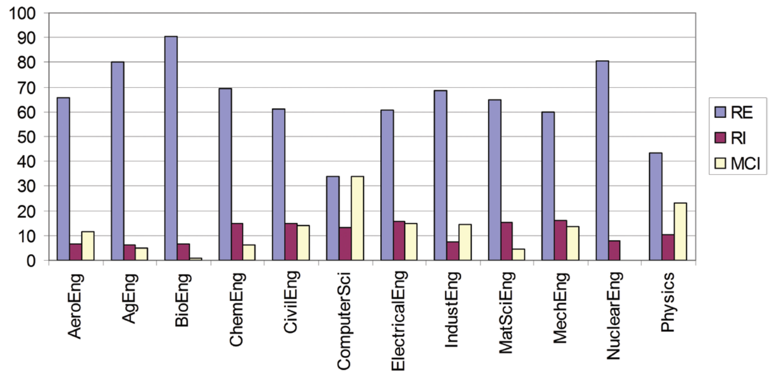

FIG. 3: Percent of engineering degrees (both genders) by major awarded by Carnegie type

but focused only on the percentage of women at an institution as a whole, finding that institutions with large engineering programs tend to have a lower percentage of female graduates than those with large education programs. Freeman et al. (2007) examined the origins of doctoral students, finding there has been a modest increase over the past 40 years toward science and engineering doctorate degrees awarded by liberal arts colleges compared with research extensive universities. Barker & Garvin-Doxas (2003) found that for computer science programs, smaller nonresearch institutions had significantly higher percentages of female graduates and that private institutions had much higher densities than public schools.

Yet, despite this evidence, most studies of engineering education continue to ignore the institutional impact on degree patterns. Using the Carnegie 2000 classification as coded in the 2007 IPEDS institutional characteristics file, engineering degrees awarded 1966–2007 were grouped by institutional type (Fig. 3). Over the last 40 years, research extensive (RE) institutions have accounted for 55.3% of all engineering degrees awarded in the fields examined here. Masters colleges I (MCI) awarded 18.9%, while research intensive (RI) institutions awarded 13.8%. No other classification accounted for more than 3% of all degrees (liberal arts baccalaureate colleges were the highest at 2.24%), and so were excluded. Masters colleges therefore constitute a significant proportion of all engineering degrees, and studies that focus solely on doctoral universities miss this critical group.

Computer science stands out among engineering majors in that masters' colleges actually award as many degrees in this field as RE institutions. For nearly all other majors, MCI's award as many or more than RI institutions, meaning they actually account for a substantial fraction of non-RE engineering degrees. Together, doctoral institutions account for 69% of all engineering degrees, while masters' colleges account for almost 20%.

RI and RE institutions have awarded nearly identical percentages of their degrees to women over the past 40 years, while masters colleges have historically had a 7% higher density of female graduates each year. However, the percentage of women graduates at

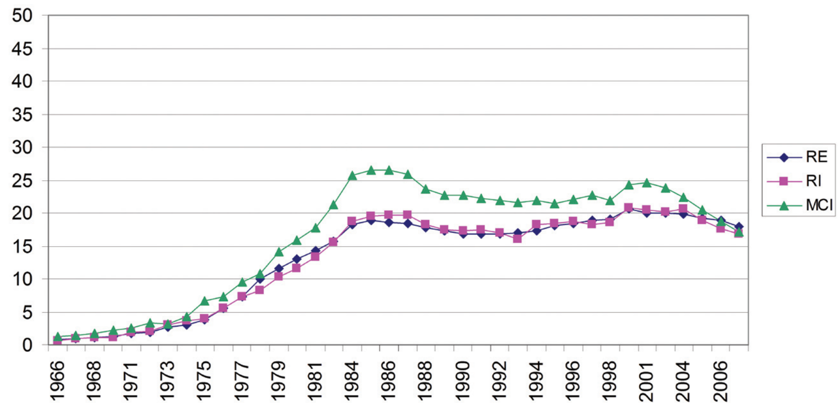

FIG. 4: Percent of engineering baccalaureate degrees awarded by Carnegie type that went to women

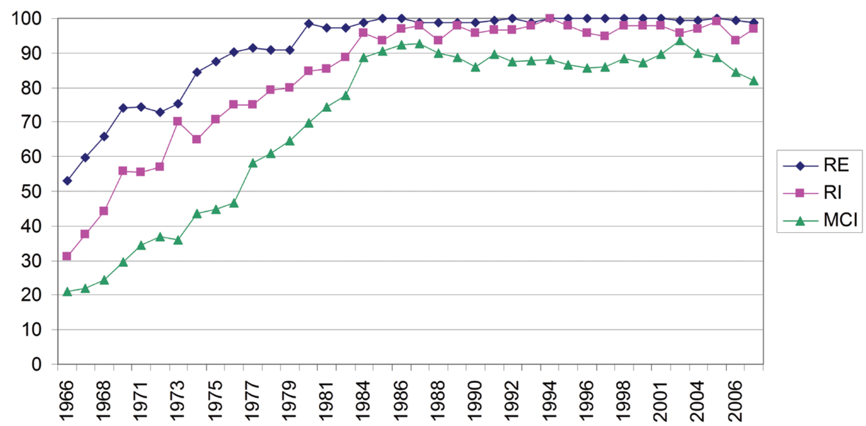

FIG. 5: Percentage of institutions by Carnegie class awarding engineering degrees to women each year

masters colleges has declined substantially over the past 4 years, such that all three institutional types now award nearly equal percentages of their engineering degrees to women (Fig. 4).

Examining the total percentage of *institutions* that award to women, on the other hand, strong stratification becomes visible between the three Carnegie types (Fig. 5). Since 1976, 90–99% of all RE institutions awarded at least one degree to a female student each year they had engineering graduates. RI institutions did not reach that level until 1983, while masters colleges took until 1985 to reach the 90% mark. Masters colleges reached a peak 93% in 2003, but have been decreasingly linearly in the 4 years since to levels not seen since 1982.

3.1 Public Versus Private

There are 149 RE institutions awarding engineering degrees in these majors, of which 68% are public, while 62% of the 100 RI institutions are public and just half of the 465 masters colleges are public. The Department of Education classifies private institutions as either for-profit or not-for-profit, but the number of engineering degrees awarded by for-profit schools is too low to generate meaningful results. From 1966 to 1984, both public and private institutions awarded roughly similar percentages of degrees to women, but private schools now award an average of 3–4% more degrees to women per year than their public counterparts, with the gap widening over the last 10 years (Fig. 6). In contrast to this, the percentage of private institutions awarding to women each year has held roughly 14% below public institutions, falling nearly 12% since 2003 (Fig. 7). This suggests that in spite of fewer private institutions awarding to women, those that do have women graduates appear to address some set of needs that draw a higher proportion of women.

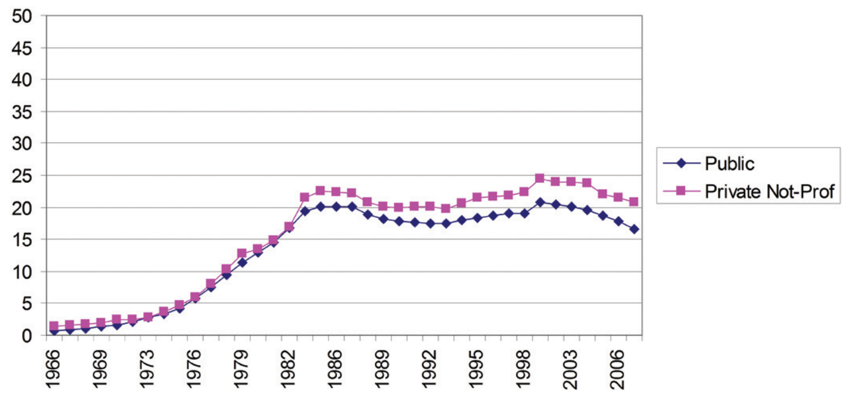

FIG. 6: Percent of engineering baccalaureate degrees awarded to women by public versus private not-profit schools

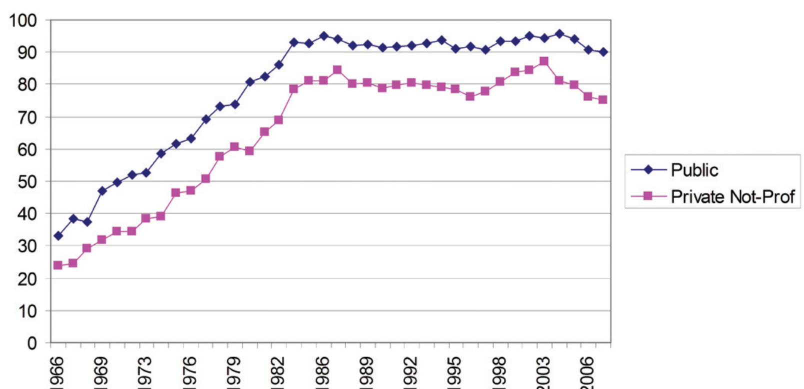

FIG. 7: Percentage of public/private institutions awarding engineering degrees to women

4. DISCIPLINARY DIFFERENCES

Differences in the gender makeup of specific majors has long been a focus of the literature on educational diversity. Countless papers such as Huntoon & Lane (2007) explore gender differences within specific disciplines, while Gurer & Camp's (2002) survey of the literature on women in computing identifies hundreds of works dating back to 1980. It is a simple fact that some engineering disciplines have a higher density of women than others. Looking across all institutional types over the past 20 years, bioengineering has had the highest representation, at 38%, while mechanical engineering has the least, at 12% (Fig. 8). Examining by Carnegie type, chemical engineering exhibits a substantially higher percentage of women in masters colleges than in RI or RE institutions, while computer science and electrical engineering have slightly higher percentages (Fig. 9).

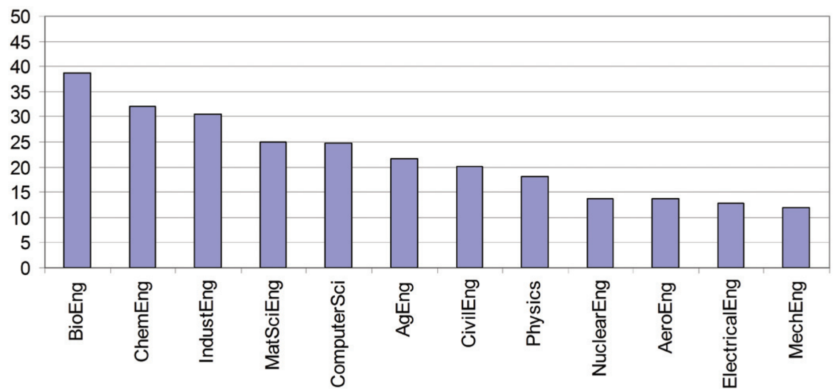

FIG. 8: Percent of engineering degrees awarded to women across all Carnegie types 1987–2007

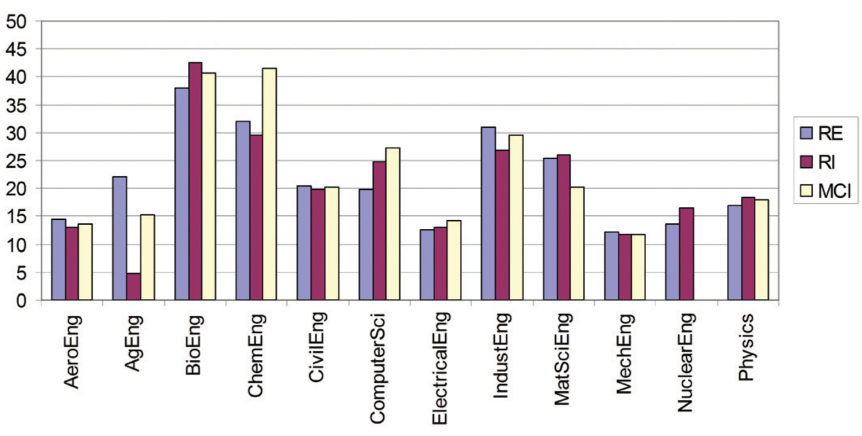

FIG. 9: Percent of engineering degrees awarded to women by institutional type 1987–2007

Each major exhibits its own unique trajectory of female graduates over the 40-year period of the reporting data (Fig. 10). The late 1970s were a turning point for most engineering majors, where they experienced their greatest growth in women graduates, while the 1990s represented a stagnation period, where the percentage of women remained steady or increased at a much slower rate. Computer science, which was largely born as a field during this period, has the sharpest increase and decrease, reflecting a new field emerging and stabilizing (Fig. 11). It peaks at 36% women in 1984 and has decreased steadily since. Yet, increases in the percent of women in a field can represent either an increase in the raw number of female graduates relative to men or a decrease of male graduates relative to women. In computer science (CS), male and female degree conferrals are strongly correlated, but the raw number of men has increased relative to women. Beginning in 2004, CS has experienced a sharp downturn in both the number of men and women graduates, with women now reaching their lowest numbers in 27 years.

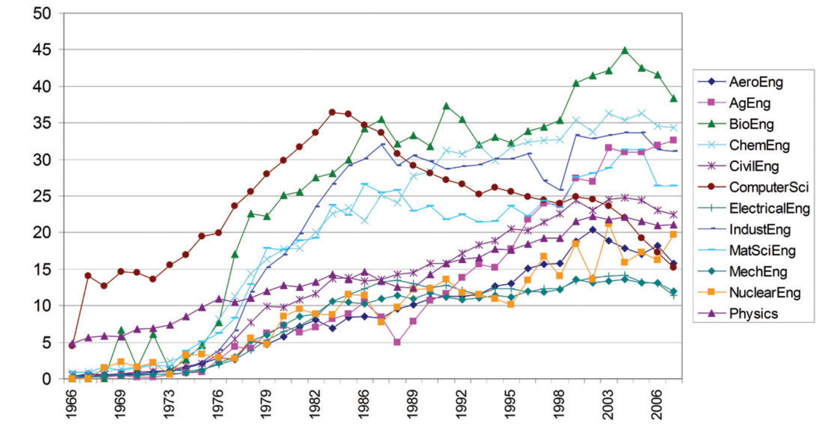

FIG. 10: Percent of engineering degrees awarded to women, by year and major

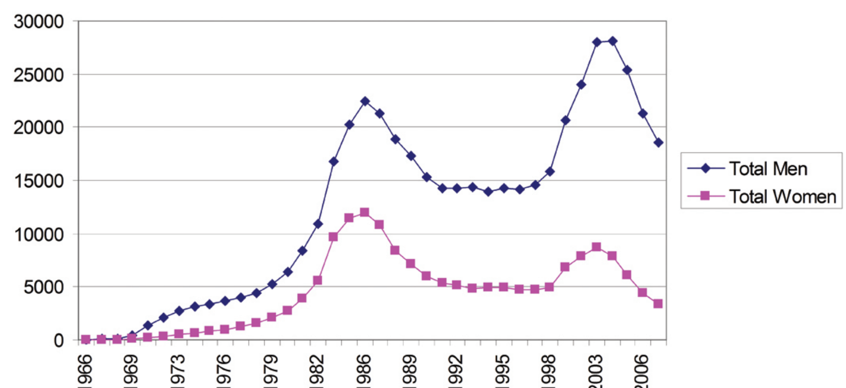

FIG. 11: Total number of degrees awarded to men and women each year in computer science

4.1 By Institution

The numbers above suggest that at any institution, women will be in the minority in their classes. For some disciplines, however, women may find that their male colleagues graduated from schools without a single woman graduate in their field that year. The average percent of institutions awarding degrees to women annually in each field over the past 20 years has a nearly 50% stratification (Fig. 12). Physics has the lowest representation, with just 55% of physics-degree-granting institutions on average having a single female graduate in a given year. Put another way, in any given year, nearly half of the institutions that grant physics degrees do not have a single female graduate. Less than three quarters of nuclear and agricultural engineering institutions award to women on average each year, while only chemical, civil, and bioengineering institutions have greater than 90% annual institutional representation over this period.

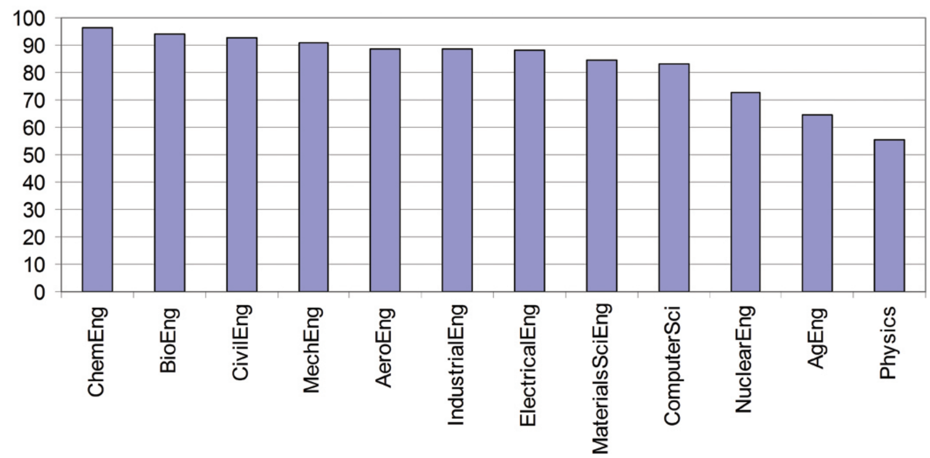

FIG. 12: Percent of institutions having at least one female graduate in an average year (last 20 years)

As with the percentage of degrees awarded to women, the overall percent of institutions graduating female engineering students exhibited its sharpest growth during the 1966–1980 period. In 1966, just 28% of all institutions awarding engineering degrees in these fields had a single woman graduate that year, a number that has increased to 81% 40 years later. Agricultural engineering has shown the greatest improvement, starting from zero in 1966 to one of the highest levels today, 95%. Physics has shown the strongest resistance to change, increasing from 23% to just 67% today (Fig. 13).

As an example of the trajectory a field can take, the number of institutions awarding CS degrees to women nearly perfectly tracked the universe of CS programs through 1987, when 92% of all institutions awarded to women. Starting the following year, however, the number of programs continued to increase at a much slower rate, while

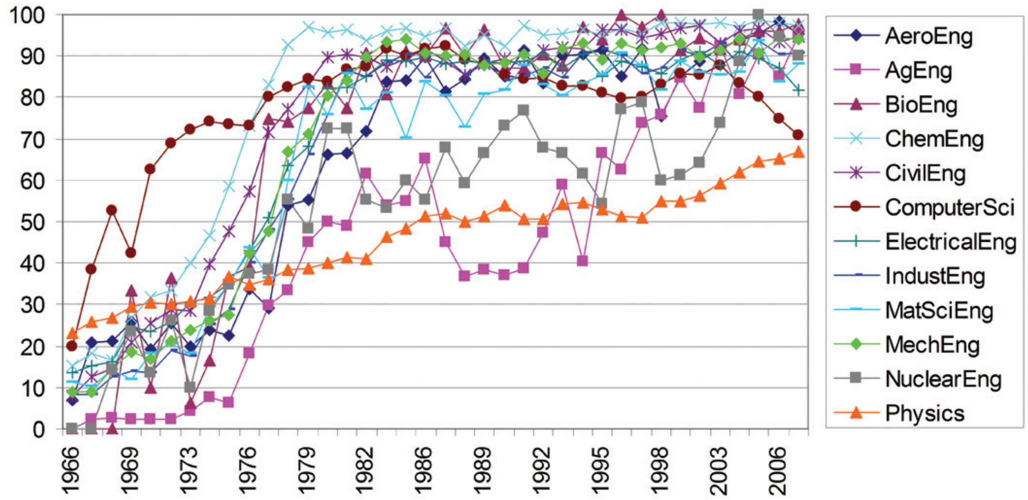

FIG. 13: Percent of engineering institutions with at least one female graduate that year

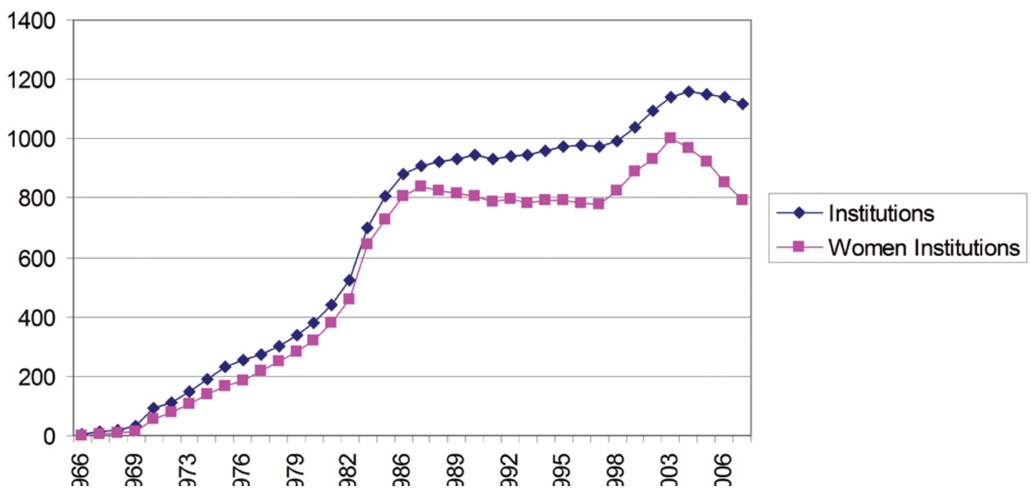

FIG. 14: Number of institutions awarding computer science degrees by year compared to number awarding to women

the number of programs with female graduates remained constant through 1997. From 1998–2003, the number of programs awarding to women nationally increased sharply, to a high of 82%, but has fallen at nearly the same rate each year since, to the lowest percent since 1972 (Fig. 14).

Some disciplines have made substantial strides toward increasing gender diversity in their programs, while others have actually seen declines. The trajectory of each program is measured as the number of years between the highest percent of women graduates to the lowest percent in the last 20 years. A positive slope indicates there has been a general increase in the percentage of female graduates in that major, while a negative slope indicates a decrease, and the magnitude of the slope is the number of years between the trough and peak (Fig. 15). CS is the only major in which all three institutional types have large negative slopes, showing there has been a strong decrease in the percentage of women CS graduates over this entire period. Agricultural, chemical, and nuclear engineering, on the other hand, have had sustained increases among RE institutions. While only 15% of electrical engineering (EE) majors graduate from masters colleges, their density there has increased from a low in 1993 to a peak as recently as 2003, at the same time their presence at RE institutions has been on a nearly 20-year decline. Without additional information it is impossible to know whether this indicates a shift of female EE students from RE to masters colleges, or whether those female students who would have graduated from RE institutions are simply dropping out or not entering in the first place.

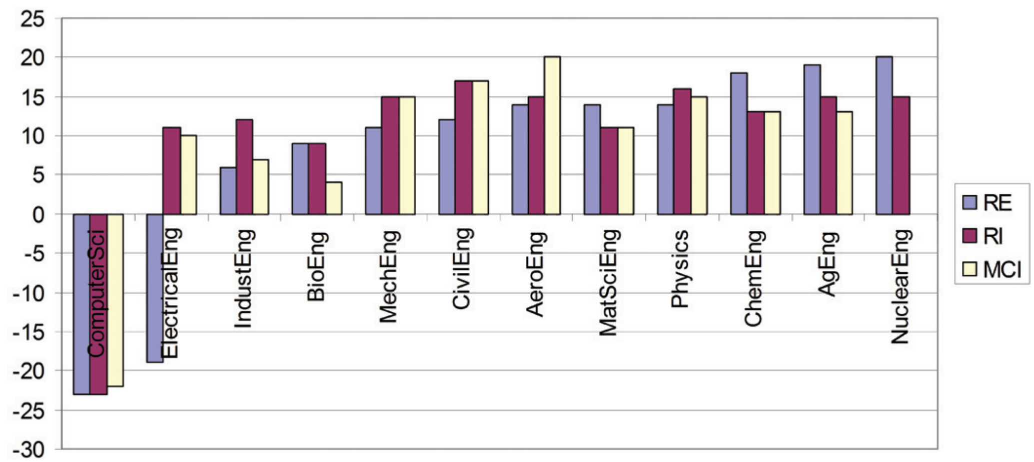

FIG. 15: Number of years between the highest percentage of women graduates 1966–2007 and lowest percentage 1987–2007

4.2 Gender Correlations

Finally, the degree to which male and female student degree conferrals are correlated in each field offers one possible indicator of the "resistance to change" of that discipline. Fields in which every increase in the number of women accompanies a corresponding increase in men suggests that dramatically boosting the density of women in that field will be far more difficult than a field in which increases of women occur more independently of male increases. Fields with inverse correlations, on the other hand, are already experiencing a strong increase in women in conjunction with a decline in the number of men, setting them on a positive course toward greater gender equity.

Masters colleges currently award 23% of all physics degrees and exhibit an inverse correlation of r=-0.35 for degree conferrals. Indeed, for those institutions, the number of women has increased linearly from 44 in 1966 to 214 in 2007, while the number of men has dropped in a zigzag fashion during that time from 1012 to 869 (although it reached a low point in 2000 and has been increasing linearly since). The only RE discipline to have an inverse relationship is materials science and engineering, in which the number of women has held relatively constant at around 200 per year, while the number of males decreased from a high of 606 in 1987 to a low of 455 in 2004, before rebounding in the past 3 years (Fig. 16).

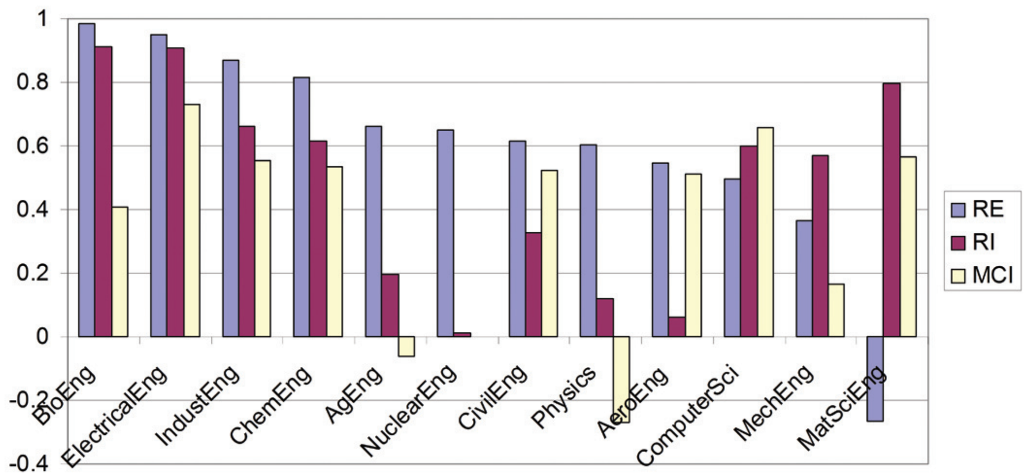

FIG. 16: Correlation of male and female degrees by major and institutional type (last 20 years)

5. GEOGRAPHIC PATTERNS

There is significant literature exploring geographic influences on the emergence of innovation centers and their characteristic development (Clark et al., 2000). It is therefore reasonable to consider the possibility that geographic location, such as regional demographic consistency, might influence the density of female engineering students. Indeed, Ohland et al. (2008) raise the question of whether the regional focus of the MIDFIELD dataset biases its results compared with other geographic localities. The two maps given here (Figs. 17 and 18) use equal interval scaling to track the total percentage of all CS and materials science and engineering degrees 1966–2007 awarded to women by institution. Red dots indicate institutions that awarded one or more degrees to men but did not award a single degree to women during this time period. Neither CS with its positive correlation of male and female degrees, nor materials science and engineering with its inverse correlation show substantial spatial impact on the density of female students among graduates of that major.

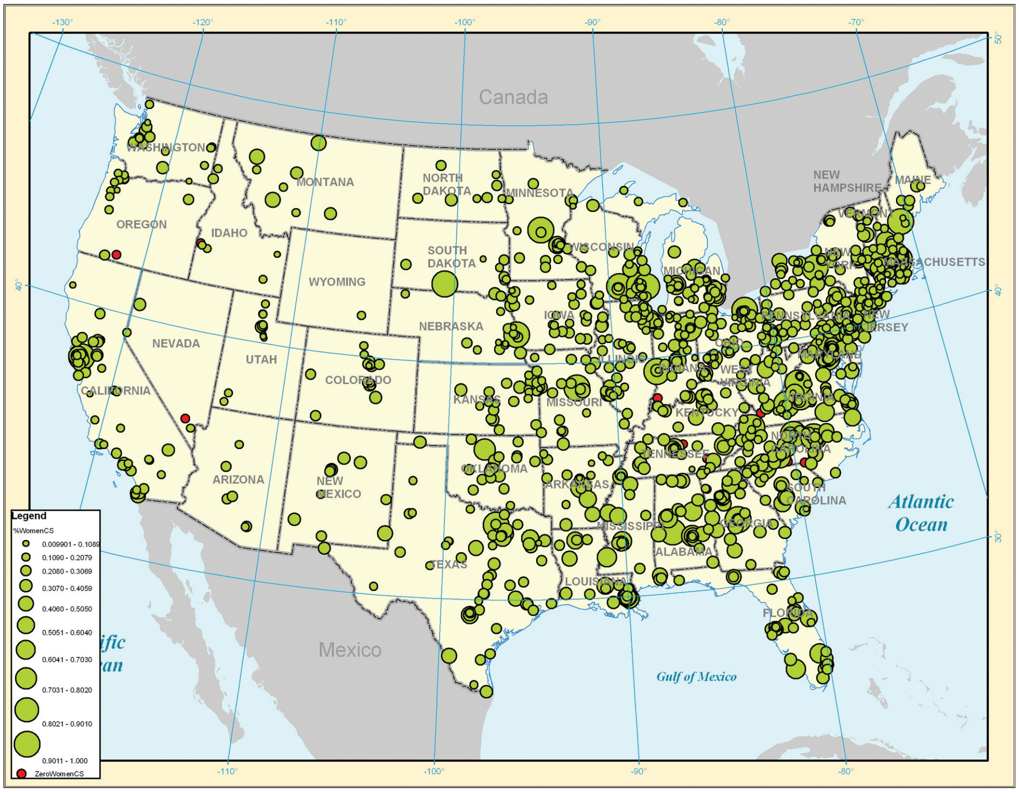

FIG. 17: Percent computer science baccalaureate degrees awarded to women 1966–2007

6. CONCLUSIONS

While previous studies tend to de-emphasize institutional differences in the engineering landscape, there appear to be significant stratification effects. Research extensive (RE) universities account for more than half of all engineering degrees awarded (55.3%), masters colleges 18.9%, and research intensive (RI) institutions 13.8%. RE and RI institutions have awarded similar percentages of their degrees to women each year over the past 40 years, while masters colleges have historically been roughly 5% higher, but this gap has closed over the past 4 years. Private nonprofit institutions have a 4% higher density of women than public ones in recent years, while 90% of public institutions award to women in an average year and only 80% of private ones do.

Majors differ significantly in the percentage of women graduating from that field, with bioengineering having the highest percent nationally at 38% and mechanical engineering the lowest at 12%. These percentages are different by institutional type, with masters colleges having a noticeably higher density of women in chemical engineering, computer science (CS), and electrical engineering. CS is the only discipline to have a significant decline in the density of women across all three institutional types over the

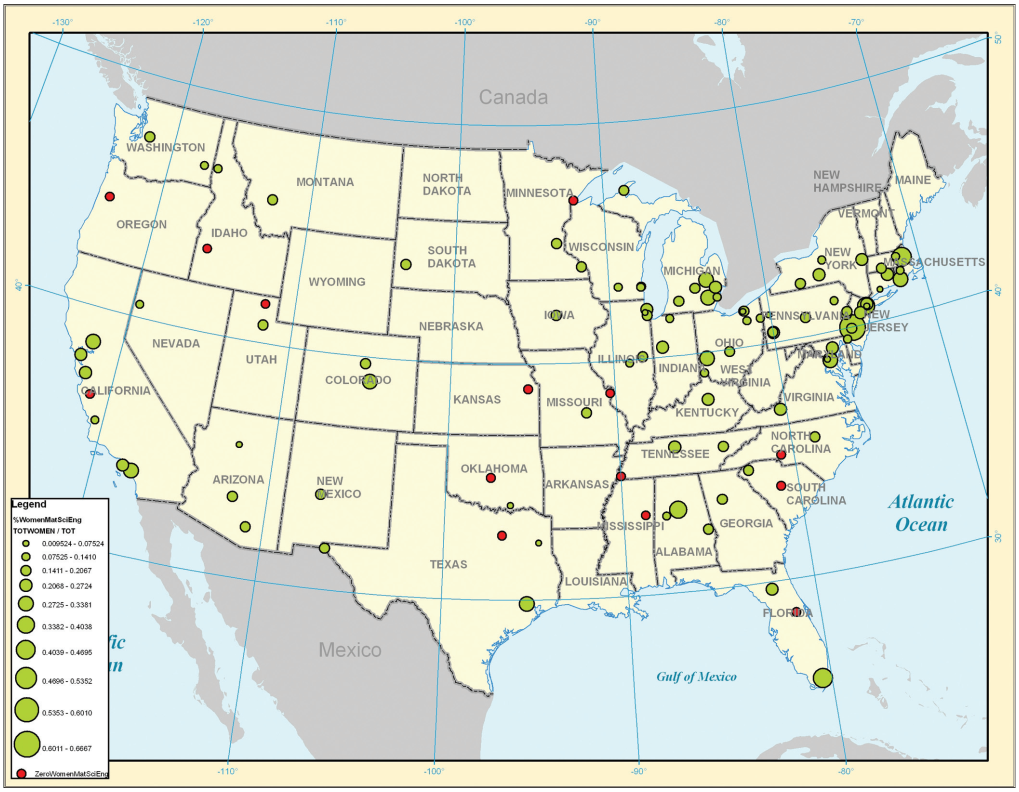

FIG. 18: Percent materials science/engineering baccalaureate degrees awarded to women 1966–2007

last 20 years. The correlation between male and female degree conferrals also varies by major, an important distinction because stronger correlations suggest that increases in female students are traditionally met by equivalent increases in male students, making it difficult to affect the overall gender balance. Only agricultural, aerospace, and materials science and engineering have inverse correlations (the first two in masters colleges), suggesting women are making significant strides in those majors.

Most studies have focused on the density of women in each major as a whole, but one surprising finding of this study is the substantial difference in the *number* of institutions awarding to women on average each year. Grouped by Carnegie type, RE institutions have averaged 99% institutional representation each year, RI's 96%, and masters colleges 88% and declining to the lowest levels since 1982. At a discipline level, only half of all institutions awarding physics degrees have a single woman graduate in an average year, while for chemical, civil, and bio engineering, nearly 90% of all institutions do so. This is a significant finding, as it suggests that efforts to attract women into the field must emphasize not only increasing the ranks of women across all institutions, but also ensuring that smaller institutions, especially masters colleges, reach a critical threshold such that all engineering graduates have at least one female student in their graduating class each year. Finally, institution location has no measureable impact on density of female degree conferrals. Overall, this study suggests that institutional factors have not been adequately explored at a national level and that future work on gender diversity in engineering must incorporate this varied landscape.

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