

Gender and graduate education in the United States: women's advancement in STEM fields

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**Gender and Graduate Education in the United States:
Women's Advancement in STEM Fields**

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Introduction

The importance of increased levels of education in improving the status of women and children throughout the world is well established. Although economists have traditionally argued that education is important for adding to human capital, we have come to understand that higher levels of education are also associated with lower birth rates (Breierova and Duflo 2004) and lower rates of infant mortality.¹ Moreover, as Amartya Sen and Martha Nussbaum have demonstrated, education adds not only to human capital but human capability, enabling women to exercise their legal rights and strengthening their political and civic engagement as well (Sen 1999; Nussbaum 2003).

Diversity in higher education has a particularly strong social and economic rationale as well. Different perspectives nurture creative thought and creative thought is needed to solve the world's most challenging problems. As studies of group dynamics have shown, greater diversity in teams encourages individual team members to do more preparation for any exercise, results in a wider range of alternatives being debated and discussed, and is more likely to generate better results (Phillips *et al.* 2011). Diversity, it seems, plays a crucial role in problem-solving, innovations, and higher productivity (Rodgers and Woerdeman 2006).

In the last third of the twentieth century, women have made particularly significant strides in gaining educational parity with men in many countries. For example, data from the United Nations Educational, Scientific and Cultural Organization indicate that women's share of enrollment in higher education in Switzerland rose from 3 percent in 1985 to 43 percent in 2000 and in France, women's share of enrollment increased from 50 to 55 percent. Women's share in Latin American colleges and universities over the same time period rose from 43 to 47 percent in Chile, and 44 to 54 percent in El Salvador. In India, women's share has risen from 30 to 39

percent.² While certainly not universal, this trend toward gender balance in student enrollment is remarkably similar in a large number of industrialized countries throughout the world (May 2008b).

The increase in women's representation among university enrollees and degree recipients is beginning to reach the highest levels of educational attainment. The Nordic Research Board (NORBAL) reports that women received 45 percent of doctoral degrees awarded by universities in the Nordic and Baltic countries in 2006—up from 27 percent in 1990 (NORBAL 2008). In the United States, in 2002, for the first time in American history, more American women than American men received doctorates from U.S. universities (Hoffer *et al.* 2003) and in 2009, for the first time, more women than men in the U.S. received doctoral degrees (Bell 2010).

Although there has been substantial growth in the representation of women in graduate education in general, they continue to be significantly under-represented in so-called STEM fields of science, technology, engineering and mathematics. Because women with STEM jobs earn approximately 33 percent more than women with non-STEM jobs, one barrier to reducing the gender wage gap remains the paucity of women in STEM fields (Beede *et al.* 2011).

Questions about how to diversify the scientific workforce have gained attention in recent years in academic circles, policy discourse, and the media. A large literature, based mostly on U.S. statistics, reveals numerous factors that influence women in scientific and technical disciplines, and why far fewer reach high positions.³ European countries exhibit the same pattern, as women remain under-represented in Europe's professional scientific employment across the business sector and academia (European Commission 2013).⁴ The low female representation comes at a cost because women bring a distinct set of skills, work styles, and attitudes to the table that can potentially affect productivity at all levels.

This study uses data from the National Science Foundation to examine how the concentration of women graduate students in various fields in U.S. graduate programs has changed over time. The analysis will also compare women's representation among the faculty at different faculty ranks with women's representation among the graduate student body across fields. Finally, we are interested in better understanding a neglected aspect of women's graduate education in STEM fields -- women students who are temporary residents receiving their education in the U.S. Results will contribute to a better understanding of gender differences in institution and field of study among graduate students and faculty as well as the extent to which gender gaps have closed since 1995. These results will thus help to improve on-going discussions of policy and institutional reforms that support diversity in academia and the labor market.

Closing the Gender Gap in U.S. Higher Education

The American system of higher education has witnessed a considerable transformation during the twentieth century, as women were increasingly enrolled in colleges and universities, particularly at the undergraduate level and later at the graduate level. The percentage of both bachelor's and master's degrees awarded to women increased from roughly 20 percent in 1900 to roughly 58 percent by 2000. Although women received less than 20 percent of all doctorates awarded from U.S. universities for the first seventy years of the twentieth century, by the year 2000, they earned 45 percent of all doctorates awarded in the United States.⁵ Moreover, the growth in women's participation at the graduate level was concentrated in the last third of the twentieth century. Women steadily increased their participation in the early years of the century, but this progress stalled in the immediate postwar era with the influx of men into higher education brought about by the G.I. Bill – a bill that provided, among other benefits, cash

payments of tuition and living expenses for returning veterans wishing to attend college. Still, the story of women's representation as students overall is one of significant progress (Jacobs 1996).

Particularly interesting are changes in graduate education in the past ten years in the US. According to data provided by the Council of Graduate Schools, we may be seeing a leveling out in the growth of women's representation in graduate education. From 2001 to 2011, total graduate enrollment in the U.S. grew at an average of 3 percent per year, with women averaging 3.3 percent growth over this period and men averaging 2.5 percent growth. A more detailed breakdown of the data shows that men outpaced women by 2.4 percent to 1.8 percent average annual growth from 2006 to 2011. While overall graduate enrollment declined from 2010-2011 for both men and women, the decline was sharper for women (-1.3 percent) than for men (-0.2 percent) (Allum *et al.* 2012).

Between 2001 and 2011, growth in total enrollment in U.S. universities was greater for temporary residents than for U.S. citizens and permanent residents. Between 2006 and 2011, total graduate enrollment increased an average 2.9 percent annually for temporary residents, compared with 2.4 percent for U.S. citizens and permanent residents (Allum *et al.* 2012).⁶

While we appear to see an overall leveling off of women's participation in graduate enrollments relative to men since 2006, the growth in enrollment of women foreign students shows increasing strength. The average annual growth in women temporary residents enrolled in U.S. schools was 3.9 percent over the period 2001 to 2011, while the average annual growth in men who are temporary residents enrolled in U.S. schools over the same period was only 1.5 percent. This may not be surprising given that women who are U.S. citizens began this period with higher enrollment levels relative to their male counterparts (61.3 percent to 38.7 percent)

than have women who are temporary residents to their male counterparts (42 percent to 58 percent) (Allum *et al.* 2012).

Trends in Women's Representation in STEM Fields

These overall trends in women's participation in higher education in U.S. institutions reveal that women now receive the majority of bachelor's, master's, and doctoral degrees. However, the women students continue to be concentrated in particular fields of study (also referred to in this chapter as fields of inquiry) that tend to be non-stem fields. In 2011, the majority of bachelor's degrees earned by women were in business, management, and marketing, while the majority of doctoral degrees awarded to women were concentrated in health professions and related programs and in law.⁷

Although women's representation in STEM fields in higher education is still disproportionately low relative to other fields, women have made progress in the past decade, especially in the sciences. Moreover, women's advancement in STEM fields has occurred at various levels, from graduate student enrollment rates to doctoral degree recipients to full-time faculty in research universities. Among fields of inquiry the overall drop in enrollments after 2010 came largely in fields such as education and from the arts and humanities, while enrollments in the STEM fields continued to grow at positive rates for both women and men.

According to the National Science Foundation, by 2010, women comprised 43 percent of all graduate students enrolled in STEM fields in U.S. universities, out of a total of more than 550,000 students enrolled (see Table 1). This percentage increased slowly in the preceding decade, up from 41 percent in 1999. These inroads have come from both scientific fields as well as engineering, where the base rate has historically been quite lower. In particular, while women made up slightly less than half of all graduate students in scientific fields in 1999, they had

surpassed the 50 percent mark by 2006. In contrast, in engineering, women made up less than a fifth of graduate students enrolled in U.S. universities in 1999, with an increase to 23 percent by 2010. Also of note in Table 1, the overall number of graduate students in the STEM fields has grown consistently since 1999, at an average rate of about 3 percent overall, with a slightly higher growth rate for women (3.2 percent) than for men (2.2 percent). These growth rates in enrollment in STEM fields are comparable to the growth rate for graduate students in all fields as reported in Allum *et al.* (2012).

Within the sciences, women have historically seen the greatest representation in psychology and in the biological sciences. About three quarters of all graduate students enrolled in U.S. programs in psychology are women, with a particularly strong increase since 1999 in clinical psychology as opposed to general or nonclinical areas in psychology. Within the biological sciences, women have a disproportionately high and still growing representation in nutrition (81 percent of graduate students in 2010, up from 76 percent in 1999). Pathology, entomology, pharmacology, physiology, and zoology are also increasingly popular fields of study for women in the biological sciences. In contrast, biometry/epidemiology is the only area within the biological sciences that has seen a decline in the relative representation of female graduate students, from 63 percent in 1999 to 59 percent in 2010. The reason for this decline is certainly not a lack of interest among women; women saw growth in their absolute numbers in this field, but the growth for men was considerably higher.

Just behind the biological sciences in terms of the representation of female graduate students are the social sciences, with a small increase of about 3 percentage points in the past decade to 54 percent in 2010. Within the social sciences, sociology and anthropology remain the most popular areas for women, while women continue to be underrepresented in economics, the

most mathematically-intense social science. Even in 2010, just 36 percent of all graduate students in economics were women. A higher, and growing, representation of women was found in agricultural economics, a more applied field that women may find more appealing. The increasing popularity of agricultural economics for women as compared to men is likely related to the very high representation of female graduate students in family and consumer science, a new field in 2010 as categorized by the National Science Foundation that uses similar analytical tools and frameworks. Also witnessing substantial growth in the past decade was the field entitled history and philosophy of science – a field in which women’s enrollment increased from 38 percent in 1999 to 45 percent in 2010.

In contrast to psychology, biological sciences, and social sciences, women have had very low representation in computer sciences, physical sciences, and mathematics and statistics. The percentage of graduate students who are female is lowest in computer sciences: just 25 percent in 2010, down from 30 percent in 1999. In the physical sciences, where one third of graduate students were women in 2010, the field of physics remains particularly low. In 2010, just one in five graduate students specializing in physics - a mathematically intensive field - were women. This imbalance is even more severe than in the field of mathematics, in which one third of graduate students were women in 2010. In comparison, women have seen a stronger increase in their relative presence in the fields of chemistry and astronomy.

The final set of results in Table 1 show women’s representation in engineering, which is almost as low as in physics. In 2010, just 23 percent of graduate students in engineering were women, up from 20 percent in 1999. Within engineering, women have relatively high rates of representation in biomedical and agricultural engineering, but very low rates in aerospace, mechanical, and nuclear engineering. Despite the very low presence of women in these fields, all

fields within engineering have seen growth over time except for nuclear engineering. Progress for women was particularly strong in agricultural and civil engineering.

Thus far this discussion has focused on all graduate students in U.S. universities, including U.S. citizens, permanent residents, and temporary residents (foreign students). For comparison purposes, it is interesting to examine U.S. students and foreign students separately since foreign students have historically been predominantly male. According to data from the National Science Foundation, while 47 percent of all U.S. students enrolled in STEM fields in U.S. universities in 2010 were female, just 35 percent of foreign graduate students in STEM fields were female (see Table 2). However, these aggregate numbers mask some interesting patterns. Although women's representation among foreign graduate students is substantially lower in aggregate, their share has risen by a greater amount over time as compared to women U.S. graduate students who are U.S. citizens and permanent residents. Moreover, the representation of women among foreign graduate students is actually higher than it is among U.S. citizens and permanent residents for several fields that traditionally have had trouble attracting and retaining women, including computer sciences, mathematics and statistics, physical sciences, and engineering. In contrast, U.S. women have a relatively higher representation as compared to their foreign counterparts in earth, atmospheric, and ocean sciences (47 percent versus 41 percent in 2010), and in the social sciences (55 percent versus 49 percent).

Examining graduate student enrollment rates by gender presents only a partial view of the state of gender equality in higher education given the well-documented “leaky pipeline” or “gender filter” along the progression from graduate school enrollment to doctoral recipients to employment as tenure-track and tenured faculty.⁸ Explanations for the leaky pipeline are

numerous and include bias, discrimination, lack of mentoring, insufficient female role models, discouragement from secondary school teachers, insufficient family-friendly policies on campuses such as paid maternity leave and a flexible tenure clock, and incompatibility of long working hours with family responsibilities. Hence the increase in women graduate students in the past decade may not have produced a proportionate increase in the representation of women among doctoral degree recipients and university faculty.

Figure 1 and Table 3 explore this question further with evidence on doctoral degrees awarded in U.S. universities in the major STEM field categories from 1999 to 2010. While we expect the total number of doctoral degrees awarded to be smaller than the total number of individuals enrolled in graduate school, the data in Figure 1 and Table 3 indicates that the percentage of doctoral degree recipients who are female is lower in most fields than the percentage of enrolled graduate students who are female. In particular, for the STEM fields in aggregate, 41 percent of doctoral degree recipients in 2010 were women, as compared to 43 percent of students enrolled in graduate school programs in the same year. The gap between doctoral degree recipients is somewhat bigger for the sciences as an aggregate (47 percent versus 51 percent). This differential in the percent female occurs for every broad field within the sciences and is especially pronounced for the social sciences (47 percent of doctoral degree recipients versus 54 percent female among enrolled graduate students) and for earth, atmospheric, and ocean sciences (41 percent of doctoral degree recipients versus 46 percent female among enrolled graduate students). Fortunately these losses in the pipeline from graduate school enrollment to awarding the doctoral degree are not as substantial as they were in 1999, with substantial shrinkage across many of the broad science categories in the gaps between women's representation among doctoral degree recipients versus enrolled graduate students. For

example, in earth, atmospheric, and ocean sciences in 1999, just 26 percent of doctoral degree recipients were women compared to 41 percent of enrolled graduate students. This gap of about 15 percentage points in 1999 had shrunk considerably by 2010. Note that these losses in the pipeline are no longer apparent in engineering in the most recent year for which the NSF report these data. In 2010, 23 percent of graduate students and 23 percent of doctoral degree recipients were women, a measure of equality not seen until after 2006.

Although the pipeline losses in the sciences still appear to be substantial as recent as 2010, Figure 1 does show a general increase in the percentage of doctoral degree recipients who are female between 1999 and 2010. This increase in the percentage of women receiving doctorates is increasing both because there have been increases in the absolute number of women doctoral recipients from year to year, and because these increases have outpaced those of men. Every STEM field across the board saw an increase over time in the percent of doctoral degree recipients who were female, with an average increase of 6 percentage points for STEM fields as a whole and for the sciences, and an increase of 8 percentage points for engineering. In most cases, both women and men received more doctorates over time in particular field areas and women's growth outpaced that of men. However, in a few fields, men saw declining absolute numbers while women continued to gain, including agricultural sciences and history of science. In fact, in agricultural sciences, a substantial drop in the absolute number of men doctoral degree recipients contributed to an increase in the percent female from 29 percent in 1999 to 46 percent in 2010.

One of the most troubling issues for women in STEM fields concerns the lower than expected entry of women PhDs into tenure-track positions. While the proportion of women receiving doctoral degrees in STEM fields has increased, the National Academy of Sciences

(2006) points out that women are more likely than men to report plans to keep postdoctoral positions, report lower satisfaction with their postdoc experience, and are underrepresented in the applicant pools for tenure track faculty positions. This argument is supported with NSF data for 2010 in Figure 2, which reports the percent of tenured/tenure track faculty who are women plotted against the percent of doctoral degree recipients who are women, for each major category in the STEM fields. For example, in the social sciences, 47 percent of doctoral degree recipients are women, while only 36 percent of tenured/tenure track faculty are women. As shown in the figure by the distance from the diagonal line, the gap between doctoral degree recipients and faculty in academia is largest in the biological sciences (a 24 percentage point gap) and smallest in computer sciences (a 4 percentage point gap).

The leaky pipeline does not stop at the assistant professor level and continues along the faculty ranks, as documented in Figures 3 and 4. Figure 3 clearly shows that for every year depicted, the percentage of faculty who are women decreases across fields of inquiry in the move from lower ranked professor positions to more highly ranked professor positions. For example, in 2010, 52 percent of non-tenured/non-tenure-track faculty in the biological and life sciences were women, compared to 43 percent of assistant professors, 31 percent of associate professors, and 23 percent of full professors. The percent female among full professors was the lowest for engineering (8 percent) and for computer and information sciences (12 percent), numbers that had risen very little since 2001. Similar to the concentration of female graduate students in psychology, Figure 3 also shows that in 2010, the highest concentrations of female faculty members at every faculty rank were in psychology, a pattern that has not changed since 2001.

Figure 4 shows that in 2010, women made up just 22 percent of full-time, full professors with science, engineering, and health doctorates in all U.S. universities, and 21 percent in U.S.

research universities. By way of comparison, in 2002, when today's younger full professors were obtaining their doctoral degrees, 38 percent of doctoral degree recipients in all STEM fields were women. This decline between receipt of the doctorate and advancement to full professor in the STEM fields is substantial. That said, there is some good news in the large jump over time in women's representation among the highest ranks of university faculty. In 1993, just 8 percent of full professors in research universities and 10 percent in all universities were women; hence the percent female has more than doubled in a seventeen-year period.

Relative Concentration of Women across Graduate Programs

To further examine the relative concentration of women's representation in STEM fields, we calculate two measures -- the Dissimilarity or Duncan Index (DI) and the Gender Concentration Quotient (GCQ). The DI is a commonly-used index for examining the segregation between two groups. As discussed in more detail in the Appendix, the DI describes in a single value the proportion of men or women who would have to change fields for there to be equal proportions of women and men in each field of inquiry.

While the DI is a convenient tool for measuring the degree of segregation of men and women in academia, it does not reveal much about the underlying nature of that segregation. That is, the DI may become smaller over time, but the reduction could result from different forces, including the introduction of more women to male-dominated fields, the entrance of more men in female-dominated fields, or a growth in integrated fields. The GCQ has the advantage of providing a continuous measure of the degree to which women are under or over-represented in a particular field (May and Watrel 2000). This measure allows us to identify male-dominated, female-dominated, and integrated fields of inquiry within the context of variations in graduate school enrollments and faculty employment by sex.

Results in Figure 5, Panel A for graduate student enrollment rates indicate that the Duncan Index for all graduate students in STEM fields has increased slightly since 1999, indicating that sex segregation across STEM fields has not diminished. Specifically, the data show that as of 2010, about 34 percent of men and women would need to change fields for there to be equal proportions of men and women in each field, up slightly from 33 percent in 1999. Patterns in the Duncan Index for all graduate student enrollments are closely mirrored by the pattern for graduate students who are U.S. citizens and permanent residents. In contrast, the Duncan Index for foreign enrolled in U.S. students is considerably lower, at about 0.28 in 2010 as compared to 0.35 for U.S. citizens. The Duncan Index for graduate students from abroad enrolled in STEM fields shows less segregation by gender than that of U.S. citizens and permanent residents. Just as the Duncan Index has risen slightly for U.S. students, foreign students have also seen a slight creeping upward in sex segregation across fields.

While the average level of the Duncan Index for doctoral degree recipients in STEM fields (Figure 5, Panel B) is comparable to the average level for all graduate student enrollments, there is more variability by year in the DI for doctoral degree recipients than for enrolled graduate students. During the 1999-2010 period, the Duncan Index for all graduate students enrolled in STEM fields averaged 0.34, which is very close to the average of 0.32 for doctoral degree recipients. However, segregation exhibited larger fluctuations from year to year for doctoral degree recipients. Moreover, the DI for doctoral degrees awarded shows a downward trend after 2005, in contrast to the increase for all graduate student enrollments.

Finally, the Gender Concentration Quotient (GCQ) allows us to better identify those particular STEM fields in which women appear to be over or under-represented among enrolled graduate students given male enrollment patterns. Figure 6, Panel A shows the “top-ten” STEM

fields in which women are over-represented among enrolled graduate students. Any field with a GCQ greater than one shows that women are over-represented given male enrollment patterns. As we can see, women are most over-represented in family and consumer science and in nutrition, with a number of the remaining top-ten fields in the social sciences. In contrast, Figure 6, Panel B shows the ten fields in which women are most under-represented given male enrollment patterns. Specifically, fields where women are most under-represented are concentrated in engineering and in physics. Clearly, more effort is required in these fields to promote and produce greater gender balance.

Overcoming Barriers for Women and STEM Fields

As we have seen, while women have made substantial progress in terms of their representation in graduate education in general in the last third of the twentieth century, they continue to be significantly under-represented in the STEM fields of science, technology, engineering and mathematics. Given the slow progress of women into many of the STEM fields, it is important to examine some of the potential barriers in these areas as well as possible policies to bring women into parity with men in these fields.

Much work has been done to chronicle our changing image of what a scientist looks like – images that prevent girls from choosing courses, majors, and careers in STEM fields and often serve as a foundation for biases and implicit barriers. Historically, when asked to “draw a scientist,” 98 percent of school age children drew males (Kahle 1987, Figure 1.1). Although this number fell in the 1990s to around 70 percent, there continues to be an implicit bias associating science with men (Rahm and Charbonneau 1997).

In related research, psychologists have found widespread implicit bias, on the part of both

men and women, associating men with science and careers and women with liberal arts and family. In their well known exercise, participants are asked to sort series of male and female names and words associated with family and career (Greenwald *et al.* 2002). The results suggest that both women and men are more likely to associate women with family and men with careers and to associate women with liberal arts and men with science.⁹

Virginia Valian explains these biases in terms of “gender schemas” – hypotheses we often unknowingly make about what it means to be male or female and hypotheses that place individuals into social groups with particular characteristics – women as nurturing and men as independent, for example. While gender schemas may be our brain’s way of sorting an immense amount of information, they also affect our judgments on competence, ability, and worth (Valian 2008).

Gender schemas may explain why it is that although in elementary school, boys and girls are equally interested in science, as children move on to their middle school years, girls have become significantly less interested in science than boys (Simpson and Oliver 1990; Jones *et al.* 2000). In a study of high school students, women were less likely to take advanced math classes than boys due to their perceived lack of ability (Pedro *et al.* 1981) -- despite the fact that studies shows no actual gender differences in average math and science achievement (Coley 2001). This trend carries on into college where fewer women enter degree programs in STEM fields.

Reasons for the dearth of women in STEM fields include the smaller proportion of women majors in these fields as undergraduates as well as attrition at all career transition points (Xie and Shauman 2003). This attrition may in part reflect the lack of women role models for women students in STEM fields. In their study of the top 50 STEM research universities, Nelson

and Rogers (2003) find that there are few female full professors in STEM fields and that the percentage of women doctoral recipients is much higher than the percentage of women assistant professors. In some disciplines, a woman can get a bachelor of science degree without being taught by a female professor in that discipline. Still other studies have focused on women's disadvantage in developing mentoring relationships with largely male faculty members. According to this view, women may be disadvantaged in the sponsorship processes (advising, mentoring, collegial) because most tenured professors are male and maintaining a professional, cross-sex relationship can be difficult. For example, Nettles and Millet (2006) suggested that female graduate students interact less frequently with male professors than do male graduate students and perceive their relationships with their mentors as less relaxed and friendly.

Studies have also shown that variations in family responsibilities between men and women may play a role. According to Xie and Shauman, marriage per se does not seem to matter, but women are disadvantaged if they have children. These women are less likely to pursue careers in science and engineering after completion of a science and engineering education and are less likely to be promoted (Xie and Shauman 2003).

Finally, at the faculty level, studies have shown that women are held to a different standard. For example, in their now famous study of Sweden higher education, Wenneras and Wold (1997) showed that women need 2.5 more publications than men to be awarded postdoctoral fellowships. Experiments examining the evaluation of research in the U.S. showed that when the identical article was scored with various gendered fictitious names – male, female, and gender neutral names – both men and women rated the article with the male name for the author superior to the article with the female name (Goldberg 1968; Paludi and Strayer 1985). Moreover, studies examining identical dossiers for hiring showed similar results depending upon

the gendered nature of the name on the dossier (Steinpreis *et al.* 1999). All of these biases create barriers for women in moving successfully in this transition from student to faculty member and affect the ability of women to be promoted.

In addition to these barriers for women, institutional barriers sometimes work to prevent women from successfully negotiating their careers in higher education. As academics, information on the processes surrounding tenure and promotion are especially important and studies have shown that male faculty report that they have a clearer understanding of their tenure prospects and standards than do women faculty (Trower and Bleak 2004). Given these reported gender differences, institutions such as faculty unions may play an especially important role for women in formalizing tenure and promotion procedures and providing faculty with greater opportunities to pursue grievances (May *et al.* 2010).

Moreover, excess service demands on women faculty have been shown to take time away from research efforts. With so few women faculty in STEM fields, women may be called upon to serve on committees to make committees more diverse and may have more demands for mentoring other female students. The diversion of effort out of research and into service activities creates additional barriers for women faculty (Fogg 2003).

Conclusion

This growing gender diversity within graduate student and faculty populations has indeed transformed knowledge. Yet women faculty members continue to be concentrated in less prestigious universities and in lower academic ranks, and they are increasingly found in non-tenure track instructional positions.

Particularly difficult is the movement of women into the so-called STEM fields. Although there has been some improvement in the representation of women faculty and graduate

students into these fields over time, our data reveal the stubborn nature of change in these fields as well as the need to examine in more detail differences between U.S. citizens and permanent residents and temporary residents in terms of women's representation.

Efforts have been made by important agencies such as the National Science Foundation (NSF) to provide programs such as the ADVANCE Program (Increasing the Participation and Advancement of Women in Academic Science and Engineering Careers) aimed at development of a more diverse science and engineering workforce.

Universities with significant STEM faculty and research have, along with other universities, instituted a number of programs to assist in the recruitment of women faculty including targeted hiring, dual career programs, tenure extensions, and easier access to childcare facilities. However, along with these important initiatives, one of the most important changes that we believe will also assist in promoting greater gender balance in these fields is the movement to formally value and encourage interdisciplinary research and research teams within the university community and in the important area of grant awards by granting agencies. Specifically, university administrators need to provide incentives and reward structures that encourage and value interdisciplinary research.

Institutional discrimination theorists argue that dominant status groups engage in practices to maintain their privileged positions (Tomaskovic-Devey 1993; Kulis 1997). Field specific values, mores, and so-called production practices are themselves chosen in order to maximize the returns to individuals already involved in the production process. Along with these practices also come elaborate screening mechanisms to control access to particular jobs. In academe, this form of institutional discrimination is reflected in the standards and rituals of scholarly conduct that affect hiring, promotion, and performance evaluation (May *et al.* 2010).

Breaking the barriers engrained in this type of institutional discrimination will greatly diminish by fostering interdisciplinary and trans-disciplinary work – or, as Elinor Ostrom, winner of the Nobel Memorial Prize in Economic Sciences puts it -- when the “silos” created by narrowly defined disciplinary structures are replace by “meadows” (May and Summerfield, 2012). Broadening the criteria for tenure to include interdisciplinary journals, valuing manuscripts in addition to journal articles in so-called “top journals,” and providing opportunities through institutional grants for collaborative cross-disciplinary research would all help to change the silo culture and promote the inclusion of women in fields where they have been under-represented while enriching current research output.

Finally, with increased pressure on finances particularly for public universities, granting agencies such as the NSF and NIH as well as a growing cadre of NGOs can play a pivotal and crucial role in providing incentives for women’s inclusion in STEM fields while improving science and solving problems. Encouraging gender balance and cross-disciplinarity in research teams on grants, reporting gender of principle and co-principle investigators in statistics on grant awards, would be especially important means of documenting and encouraging greater gender balance. As our research shows, there is much work to be done to achieve greater gender balance in the STEM fields but creative and workable solutions are indeed possible.

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Appendix: Duncan Index and Gender Concentration Quotient

The Duncan Index describes the proportion of all women or men in the sample who would have to change fields of inquiry in order to equalize the distributions of fields between men and women. The DI, which is commonly used to describe the extent of occupational segregation in the workforce, is defined as:

$$DI = \frac{1}{2} \sum_i | \alpha_{mi} - \alpha_{fi} |$$

where α_{mi} is the share of male graduate students in the sample enrolled in field i , α_{fi} is the share of female graduate students in the sample enrolled in the same field i , and i sums across all fields of inquiry. The Duncan Index ranges from zero (complete integration) to one (complete segregation). For example, if women make up 46 percent of all graduate students, an index of zero would mean that women make up 46 percent of the graduate students in any given field of inquiry. Alternatively, an index of one would indicate total enrollment segregation by sex; and an index of 0.75 would mean that three quarters of women would need to change fields for there to be equal representation of women and men by field.

The Gender Concentration Quotient in each field i is:

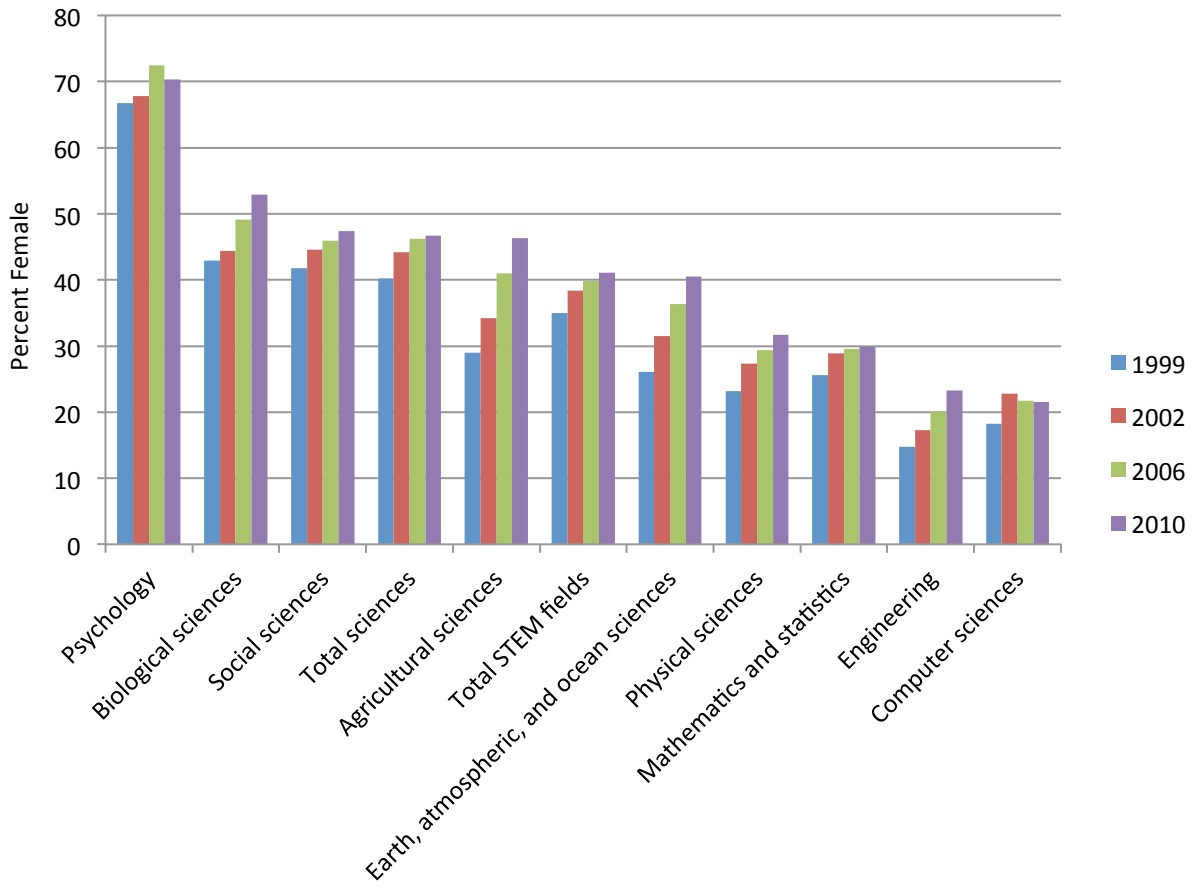
$$GCQ_i = F_i / F_i^* , \text{ where } F_i^* = \alpha_{mi} \times TF .$$

In this case, F_i is the actual number of female graduate students enrolled in field i and F_i^* is the expected number of female graduate students enrolled in field i if women were enrolled in field i in the same proportion that men are enrolled in field i . Thus, F_i^* is derived by taking the proportion of male graduate students enrolled in field i (α_{mi}) multiplied by the total number of female graduate students in all fields of study. The GCQ allows us to examine the actual number of women enrolled in a field, compared to the expected number of women who would be enrolled if women were distributed among fields in the same proportions that men are distributed

among fields. As such, the GCQ utilizes what economic historians refer to as a counterfactual framework — a framework that compares actual female enrollment patterns with a hypothetical pattern that would exist if women were enrolled in fields in the same proportions as men.

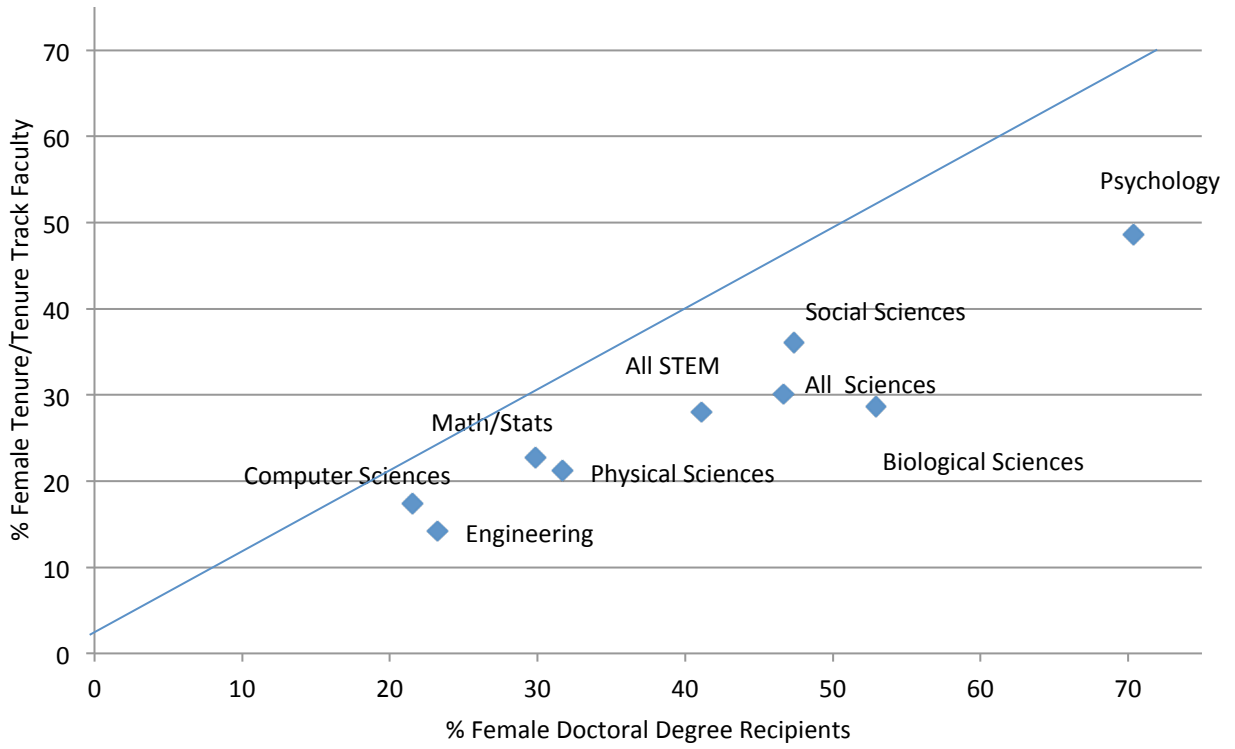
The GCQ can be interpreted in the following manner. If the GCQ in a particular field is greater than one, then more women are enrolled in that field than would be expected on the basis of men's enrollment patterns. If the GCQ is equal to one, then the number of women that are enrolled in that field equals the number expected on the basis of men's enrollment patterns. And, if the GCQ is less than one, then fewer women are enrolled in that field than would be expected on the basis of men's enrollment patterns. Thus, a GCQ greater than one represents a female-dominated field, less than one represents a male-dominated field, and equal to one represents a field in which men and women are roughly equally represented given their overall enrollment in graduate school. The GCQ provides information about whether a particular field retains more women than would be expected, given the enrollment patterns of men. The GCQ allows us to identify fields which are male-dominated (those with a low GCQ), female-dominated (those with a high GCQ), or integrated (those in which the GCQ is equal to one). In addition to allowing us to identify these three categories of fields, the gender concentration quotient has the advantage of providing a continuous measure of the degree of segregation across fields in graduate school.

Figure 1: Doctoral Degrees Awarded in STEM Fields in U.S. Universities: Percent Female, 1999-2010



Sources: Calculated from data in NSF (2009, 2013).

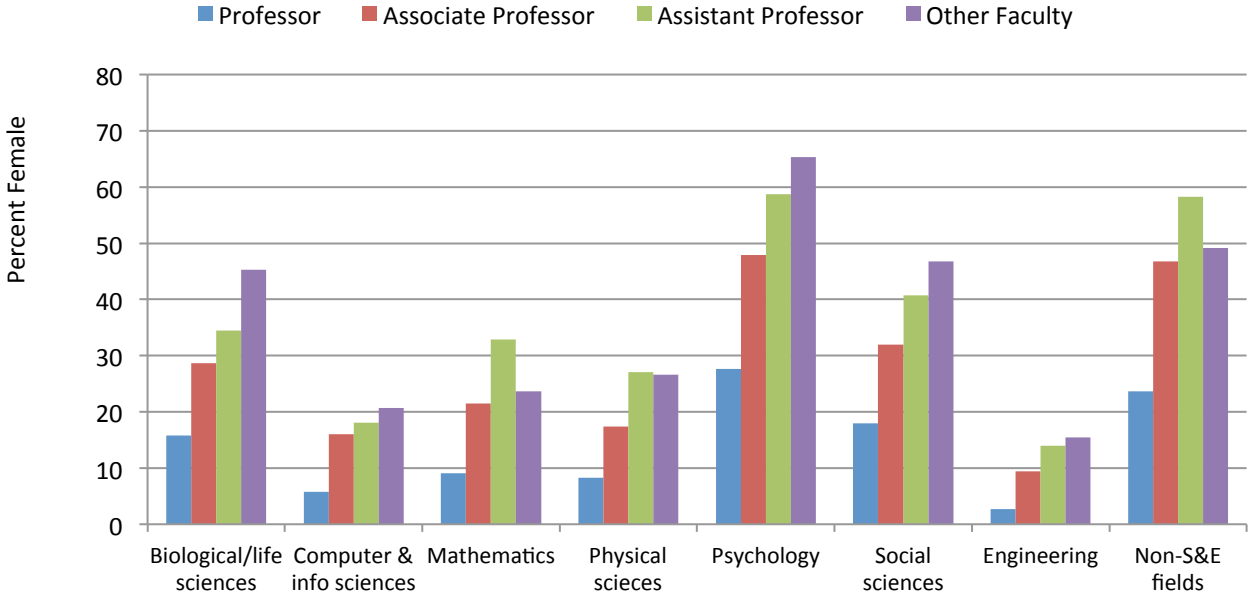
Figure 2: Doctoral Degrees Awarded and Tenured/Tenure Track Faculty in STEM Fields in U.S. Universities: Percent Female, 2010



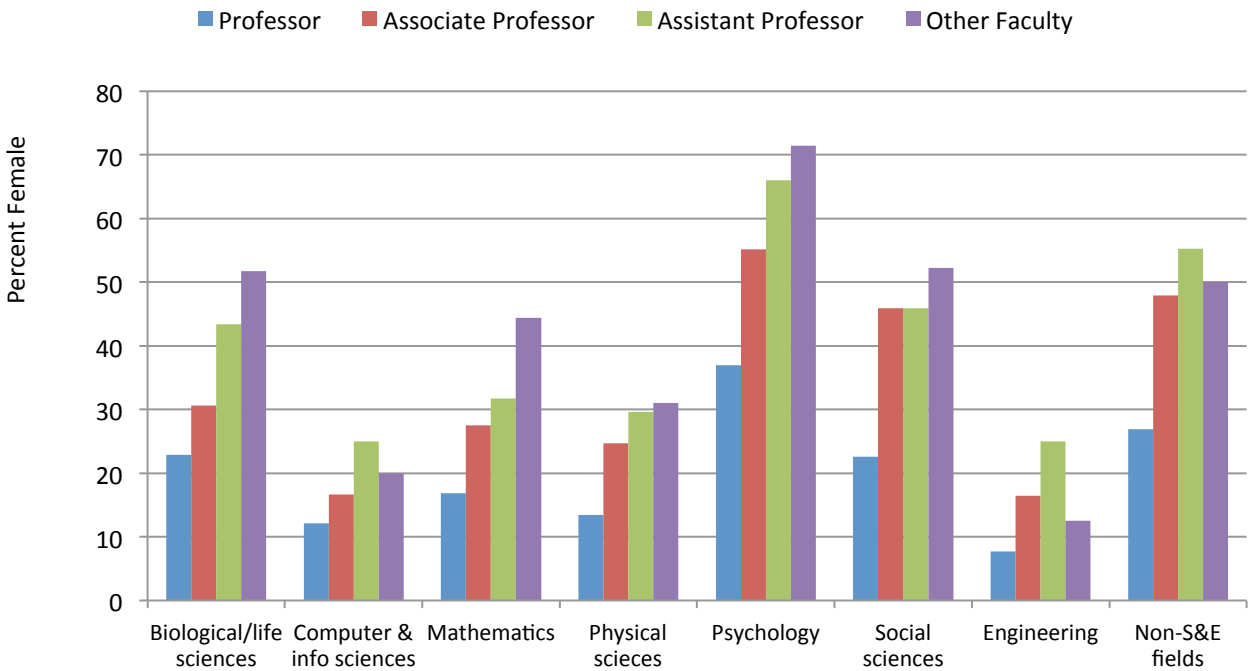
Source: Calculated from data in NSF (2013).

Figure 3: Female Representation Among Faculty with Doctorates in Science, Engineering, and Health, by Faculty Rank and Field, 2001-2010

Panel A: 2001

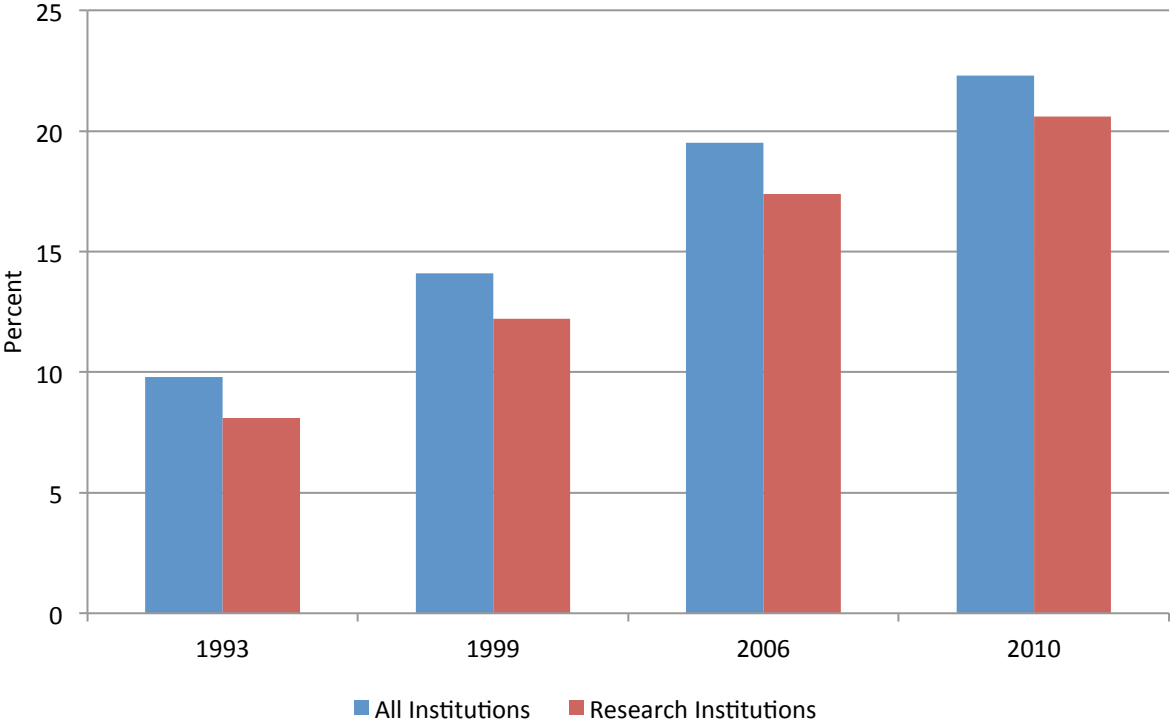


Panel B: 2010



Sources: Calculated from data in NSF (2004, 2013).

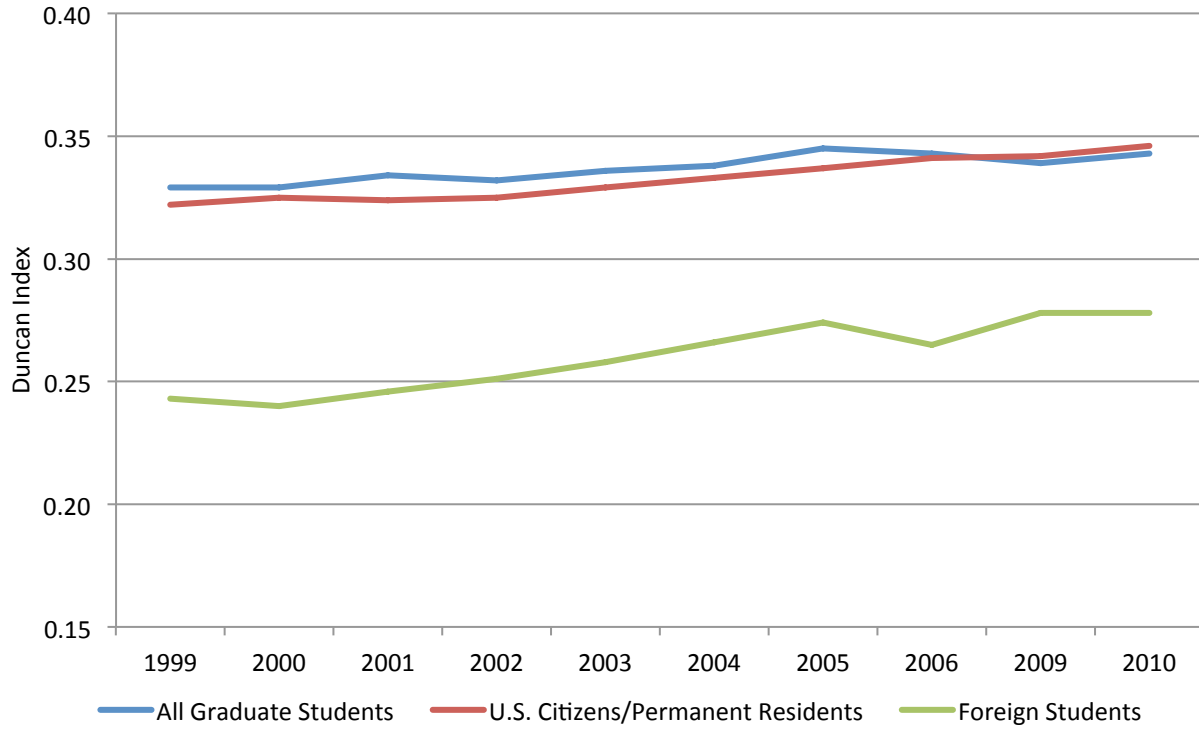
Figure 4: Female Representation Among Full Professors with Doctorates in Science, Engineering, and Health: 1993-2010



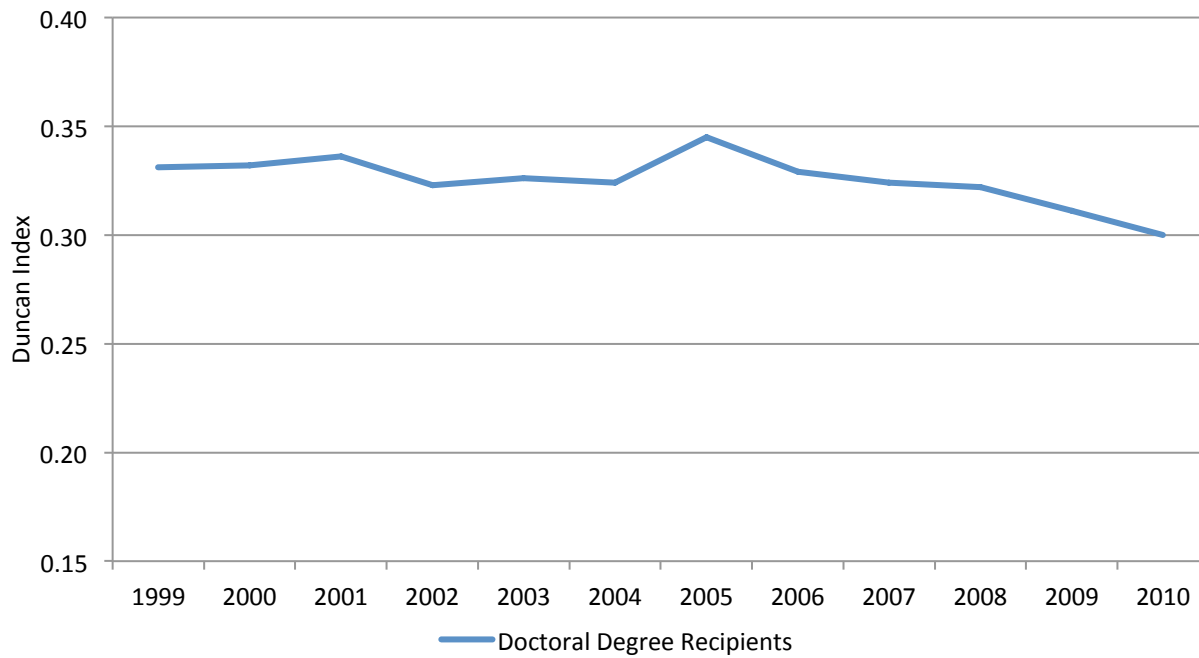
Source: NSF (2013).

Figure 5: Duncan Index of Dissimilarity for Graduate Students in STEM Fields, 1999-2010

Panel A: Graduate Student Enrollments



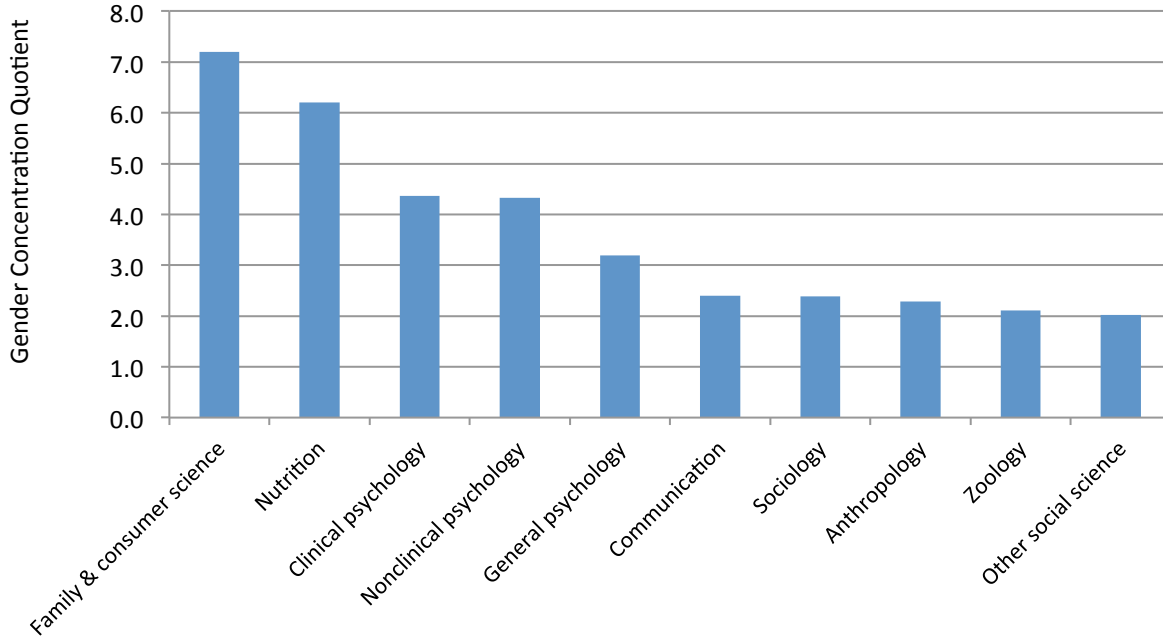
Panel B: Doctoral Degree Recipients



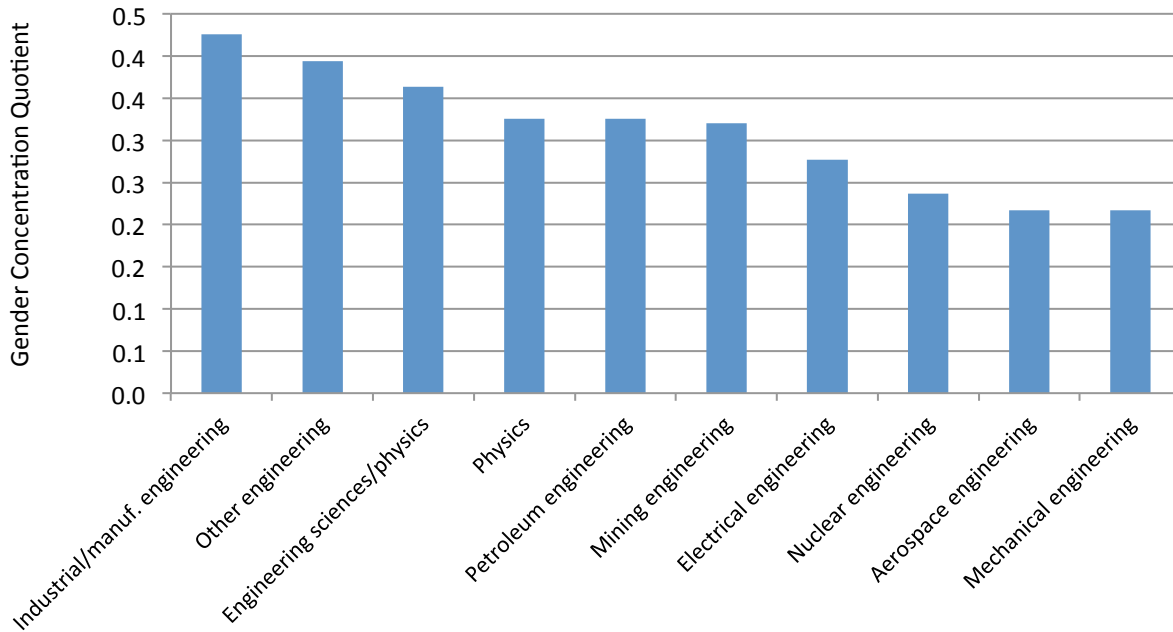
Sources: Calculated from data in NSF (2007, 2011, 2013).

Figure 6: Ranking of Fields of Inquiry by the Gender Concentration Quotient, 2010

Panel A. Top Ten Fields for Female Graduate Students with the Highest GCQ



Panel B. Bottom Ten Fields for Female Graduate Students with the Lowest GCQ



Calculated from data in NSF (2007, 2011, 2013).