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CHAPTER 16

Retention and Persistence of Women and Minorities Along the Engineering Pathway in the United States

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Introduction

Countries around the world rely on the contributions of engineers to support national interests and maintain economic competitiveness. In the United States, government and industry leaders have long regarded engineers and other members of the science, technology, engineering, and mathematics (STEM) workforce as vital to the nation's economy and security. It is hardly surprising, then, that issues surrounding student retention and persistence in engineering degree programs and the engineering workforce are of special interest to engineering educators.

Since the 1970s, federal policy and funding have specifically focused on attracting and retaining women and minorities in science and engineering fields. Yet progress has been halting. In one comprehensive study, the United States ranked 30th of 35 countries in the proportion of female Ph.D.s in engineering, manufacturing, and construction, and 24th of 30 with respect to growth in the proportion of female Ph.D.s in these sectors (European Commission, 2009, p. 51).[1] In this chapter, we examine the influence of U.S. federal policy on engineering education over the past forty years, with special attention to the impact of efforts to increase the numbers of women and minorities in the STEM workforce.

The National Science Foundation Seeks a STEM Workforce

In the history of engineering education in the United States, few events have proven more decisive than the creation of the National Science Foundation (NSF). The agency was formed in 1950 "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense. . . . " (National Science Foundation Act of 1950, Public Law 81-507). One of the agency's core missions is to "cultivate a world-class, broadly inclusive science and engineering workforce" to ensure that the nation produces sufficient numbers of scientists and engineers to keep the United States at the forefront of scientific discovery

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and technological innovation (http://www.nsf.gov/about/).

Because NSF allocates significant funding to these efforts, attracting talented individuals to careers in STEM fields has become a central theme in STEM education research. NSF administers a total of $1.2 billion annually, or 34%, of all federal dollars ($3.4 billion) spent on STEM education. This investment is the largest expenditure for this purpose by any federal agency. Moreover, NSF is the only agency that houses programs devoted solely to engineering education. Nearly all these funds are for programs and initiatives designed to promote STEM education and workforce development; the annual investment dedicated to engineering education research is only $14 million, or less than 0.05% of the total federal STEM education annual investment (Committee on STEM Education, 2011).

*1970–1985: **Expanding the STEM Workforce by Targeting Women and Minorities***

For decades, efforts to create a talented STEM workforce focused on the population stereotypically associated with science and engineering. The average scientist was "a 30-year old [white] male from the middle-Atlantic states (usually New York) with a Ph.D., ten years or less experience in the field, was employed in either academia or in industry, and more likely to know German than Spanish" (Lucena, 2005, p. 51; NSF, 1964). During the 1970s, however, this focus began to change. Concerns about threats from other countries receded as concerns about domestic issues, from poverty to environmental degradation, came to the fore. Leaders of organizations and academic institutions that predominantly served minorities argued to Congress that problems afflicting inner-city communities could best be addressed by applied scientists who came from and were knowledgeable about those communities (Lucena, 2005).[2] Also during this period, the second wave of the feminist movement was expanding traditional conceptualizations of science and of the role of women in scientific fields (Espinosa, 2011; Keller, 1985).

Both the civil rights and the women's movements impacted federal policymaking. In one notable example, Janet Welsh Brown, head of the American Association for the Advancement of Science (AAAS) Office of Opportunities in Science and president of the Federation of Organizations for Professional Women, testified before Congress, calling for greater efforts by NSF to broaden participation of women and minorities in the sciences (U.S. Congress, House Committee on Appropriations, 1976). Brown was also a co-author, with Shirley Malcom and Paula Hall, of *The Double Bind: The Price of Being a Minority Woman in Science*, a report still referenced today for its analysis of the challenges women – and women of color in particular – face in overcoming gender and ethnic bias in the pursuit of science and engineering careers (Malcom, Hall, & Brown, 1976). Armed with statistics showing the dearth of minority and female scientists, Brown and other leaders were powerful advocates for policies and funding to increase the numbers of minorities and women in STEM (Lucena, 2005).

Such efforts resulted in the Science and Technology Equal Opportunity Act of 1980 (PL96-516).[3] Enacted thirty years to the day after the first NSF executive board meeting, the Act made promoting scientific and engineering talent among women and minorities a federal priority:

> *The Congress finds that it is in the national interest to promote the full use of human resources in science and technology and to insure the full development and use of the scientific talent and technical skills of men and women, equally, of all ethnic, racial, and economic backgrounds.*[4]

By the mid-1980s, economic competition from Japan, combined with a recession in the United States, renewed concerns about identifying and training a workforce to preserve U.S. global technological superiority. The Committee on the Education and Utilization of the Engineer, formed by the National Research Council (NRC),

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set about forecasting the availability of a sufficiently trained science and engineering workforce (NRC, 1986). In 1986, the Committee, whose members were all engineers, created a mathematical "flow model" based on the balance equation from traditional energy and material balances.[5] The reports presenting this model were accompanied by an elaborate schematic that looked rather like a diagram of a complex computer circuit. The language of "flow," "input," and "output" that accompanied the figure led very naturally to a vivid and powerful *pipeline* metaphor, which drove policy and research for the next twenty years. Indeed, the pipeline metaphor persists today, in spite of attempts to supplant it with a more expansive *pathways* metaphor that accommodates multiple points of entry, exit, and reentry (Adelman, 2006; Atman et al., 2008; Sheppard, Macatangay, Colby, & Sullivan, 2008).

The NRC Committee's mathematical model in 1986 projected a 5% decrease over the following decade in the college enrollment of White male 22-year-olds, the primary population that until then had earned bachelor's degrees in science and engineering. At the same time, analysts noted increases in the number of bachelor's degrees awarded to minorities and women during the previous five years and speculated that women and minorities could be relied on to fill the gap left by the sagging numbers of White males. From then until now, researchers and policy analysts looking for ways to bolster the STEM workforce have emphasized the need to encourage greater participation among women and underrepresented minorities (Hartline & Poston, 2009; Nelson & Rogers, 2007; Satcher, 2001).

1986–2000: Retention and Persistence Emerge as Obstacles for the STEM Workforce

Even as the U.S. government established an imperative to increase the numbers of women and minorities in science and engineering, several research articles and policy reports from the mid-1980s to the early 1990s documented low retention rates for all students in science, engineering, and math, especially among minorities and women. One federal report found that 50% of undergraduates entering science and engineering programs did not complete degrees in those fields, and only 30% of those who did complete degrees went on to graduate school (U.S. Congress, Office of Technology Assessment, 1989). Other studies reported disproportionately low interest and participation in STEM fields among women and minorities. Minorities accounted for less than 6% of undergraduate engineering degrees awarded in 1984. In 1986, only 2.7% of female undergraduates reported an intention to major in engineering, compared to 17.8% of males (see Malcom, George, & Van Horne, 1996). If women and minorities were to fill the need for talented individuals in the STEM workforce, their participation in STEM majors, and their rates of completion of STEM degrees, would have to increase.

The seminal work to come out of this research was – and still is – *Talking About Leaving*, by Elaine Seymour and Nancy Hewitt (Seymour & Hewitt, 1997). The authors relied primarily on qualitative data (interviews) to explore patterns of persistence and switching among more than 345 undergraduates from seven diverse colleges and universities. Seventy-three percent of the students in the sample were White, and 27% were people of color (African American, Native American, Hispanic, Japanese, Chinese, Laotian, Pakistani, Cambodian, Korean, and East Indian). In both groups, just over half of the students were women.

Talking About Leaving provided a vivid picture of the challenges faced by many who pursued STEM majors. The data showed that those who left science, math, and engineering (SME) and those who did not had similar capabilities, as indicated by grade point averages and SAT scores. Differences between switchers and persisters had to do with perceptions of and attitudes toward the culture and climate of science and engineering classrooms and majors. Seymour and Hewitt found that faculty teaching

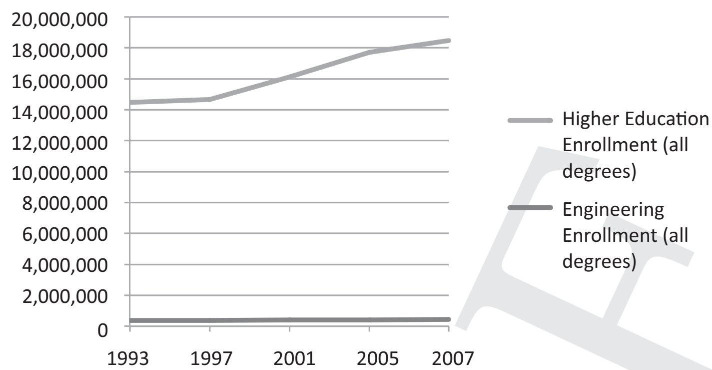

Figure 16.1. Snapshot 1: Engineering degree enrollment (all degrees) compared to higher education enrollment (all degrees), 1993–2007. (*Source*: National Science Board (2010). Science and Engineering Indicators – 2010. Appendix tables 2–4 & 2–15. Arlington, VA: National Science Foundation (NSB 10–01). Retrieved from http://www.nsf.gov/statistics/seind10/c/cs1.htm.

styles and other environmental factors affected students differentially, ultimately causing many women and students of color to migrate out of SME programs and into programs they perceived to be more compatible with their goals and learning styles.

Seymour and Hewitt's work had two effects that continue to shape today's research into STEM retention and persistence. First, *Talking About Leaving* married concerns about recruitment of minorities and women into STEM with the issue of undergraduate retention. Second, Seymour and Hewitt argued that improving minority and female retention would require changes in classroom instruction and institutional policies in higher education. These findings prompted a fundamental shift from forty years of prior research and policy on the STEM workforce. Whereas previous efforts were aimed at identifying talented individuals and recruiting them into STEM fields, Seymour and Hewitt focused attention on retaining those who demonstrated both the interest and capacity to succeed. Notably, the kinds of changes advocated in *Talking About Leaving* in order to sustain motivation and increase the retention and persistence of minorities and women in STEM were eventually recognized as advantageous not just for those groups, but for *all* students pursuing STEM majors (Kyle, 1997).

STEM Retention and Persistence Today

Policy and research documents continue to argue that the United States needs a diverse STEM workforce to address a broad range of domestic and international challenges (Committee on Prospering in the Global Economy of the 21st Century, 2007; Committee on Underrepresented Groups and the Expansion of the Science and Engineering Workforce Pipeline et al., 2011; Hartline & Poston, 2009). However, while enrollment in science fields has increased relative to higher education enrollment overall, engineering enrollment as a proportion of higher education enrollment has declined (see Figure 16.1).

Although the proportions of women and underrepresented minorities enrolled in undergraduate programs generally have increased since the 1980s, minimal progress has been made in recruiting and retaining students, and especially women and minorities, into engineering programs (see Figure 16.2).

At all postsecondary academic levels and in the workforce, women are underrepresented in engineering and in many scientific fields, with the exception of biological sciences (Committee on Underrepresented Groups and the Expansion of the Science and Engineering Workforce Pipeline et al.,

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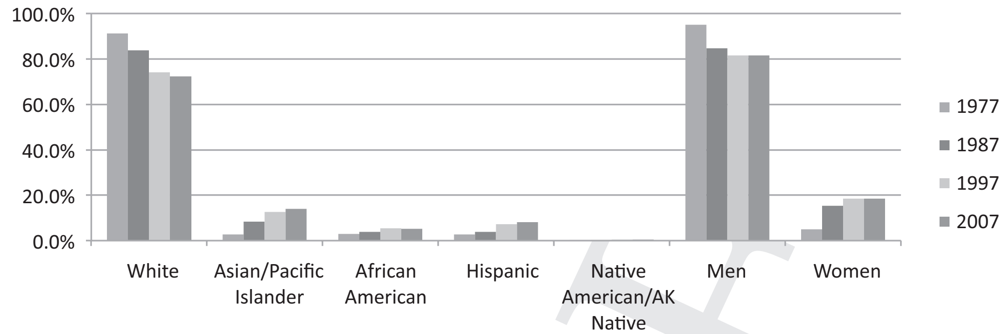

Figure 16.2. Snapshot 2: Engineering bachelor degrees awarded by race and gender, 1977–2007. (*Source*: 1977–1997 data: National Science Foundation (2002). *Science and Engineering Indicators – 2002*. Tables 2-16 & 2-17. Arlington, VA: National Science Foundation, 2002 (NSB-02–1). Retrieved fromhttp://www.nsf.gov/statistics/seind02/intro/acknowl.htm#top2007 data: National Science Foundation (2010). *Science and Engineering Indicators – 2010*. Tables 2-12 & 2-13 (appendix). Arlington, VA: National Science Foundation (NSB 10–01). Retrieved March 31, 2012 from http://www.nsf.gov/statistics/seind10/c/cs1.htm).

2011; Ong, Wright, Espinosa, & Orfield, 2011). In fact, women are underrepresented in two ways. First, women who are not White or Asian are significantly underrepresented in higher education relative to their proportion of the general population. Second, women of all races are underrepresented in engineering (17.9%) relative to the proportion of total undergraduate degrees they earn (57.5%) – see Figure 16.3.

Women and minorities continue to face the same obstacles first reported fifty years ago; yet the issues are better documented now than they were in the past. Furthermore, research has revealed strategies that successfully promote the retention and

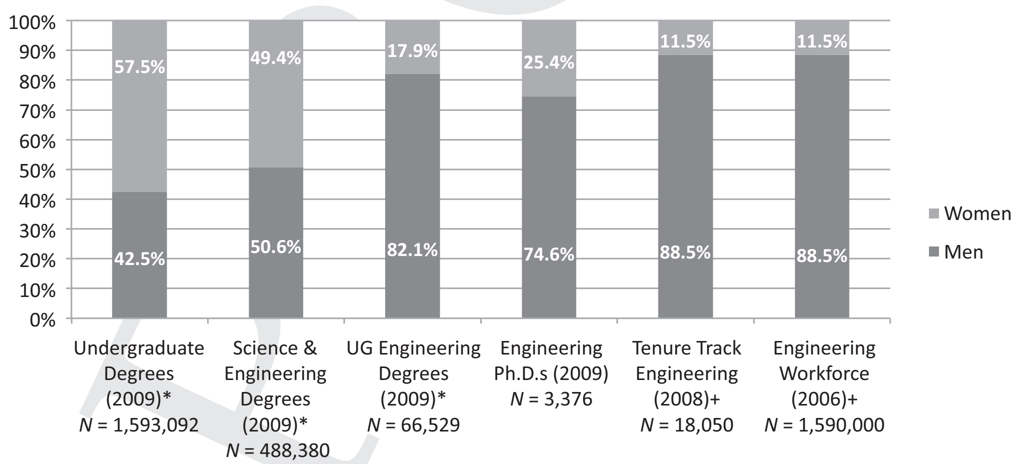

Figure 16.3. Engineering attainment at career junctures by gender. (*Sources*: *National Science Foundation (2011). *Women, Minorities, and Persons with Disabilities in Science and Engineering: 2011*. Special Report NSF11–309. Division of Science Resources Statistics. Updated January 2012. Table 5-3. Arlington, VA. Retrieved from http://www.nsf.gov/statistics/wmpd/.
+National Science Foundation (2011). *Women, Minorities, and Persons with Disabilities in Science and Engineering: 2011*. Special Report NSF11–309. Division of Science Resources Statistics. Updated January 2012. Tables 7-2, 9-26, 9-7.)

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persistence of all populations, including women and minorities, in STEM majors and careers. The remainder of this chapter provides an overview of the literature, followed by a discussion of effective approaches to developing a strong, diverse STEM workforce.

Understanding Persistence and Retention

Before reviewing the relevant research, we provide some groundwork for discussing *persistence* and *retention*. Much of the research in these areas looks at students in engineering and in the sciences collectively. Those studies that disaggregate data show varying profiles of retention and persistence across STEM fields. Interestingly, engineering as a whole has higher overall retention than other science and technology fields, but less participation by women. There are also dramatic differences within engineering disciplines. Having said that, we believe that findings across engineering and the sciences differ more in degree than in kind, and we would be overlooking important lessons if we focused exclusively on studies of retention and persistence in engineering. Therefore, the body of literature reviewed in this chapter includes a judicious combination of studies dealing with engineering generally, with engineering subfields, and with engineering and science disciplines more broadly.

In the discussion that follows, *retention* refers to remaining in STEM during each phase of one's education or career (e.g., completing an engineering degree). *Persistence* refers to making the transition from one career juncture to another (e.g., progressing from an undergraduate STEM program into a graduate STEM program). Lowell, Salzman, Bernstein, and Henderson (2009) propose a similar framework that examines retention and persistence during the periods from high school to STEM undergraduate degree (five years after high school), completion of STEM undergraduate degree to first job (three years after college), and completion of STEM degree to employment in STEM occupation at mid-career (ten years after college completion).

It is with some hesitation, however, that we adopt this distinction between retention and persistence, for we recognize that doing so risks fragmenting the research literature. For example, we have used the word "persistence" in the titles of previous articles, referring to what we are now calling "retention." But we believe that *not* making the distinction fragments the research in a more troublesome way, because using the terms "retention" and "persistence" interchangeably glosses over significant challenges faced by women and people of color navigating STEM pathways.

Literature Review

Persistence Along the STEM Pathway

The landscape of research into persistence in engineering and the sciences is extremely nuanced. Findings vary by gender as well as by race and ethnicity (Johnson, 2011). Yet in spite of apparent contradictions at a superficial level, careful observation of specific populations and subpopulations yields consistent and revealing trends.

Persistence from High School to Two- and Four-Year Colleges and Universities

Several studies have shown that young women and minority high school students and undergraduates are as likely as young White men to express an interest in or intention to pursue an undergraduate STEM degree (Hurtado, Eagan, & Chang, 2010; Riegle-Crumb & King, 2010; Staniec, 2004; Varma & Hahn, 2007). There is also evidence that young women are no less qualified than young men to pursue STEM careers. Students who complete college degrees in engineering and the sciences have usually taken higher levels of high school math and/or scored well on the Advanced Placement math exam compared to their peers. The K–12 gender gap on these important indicators, significant in the past, has closed over the past two decades, with females performing comparably to males on most measures of math and science achievement (AAAS, 2010; Freeman, 2004; Peter & Horn, 2005). On the other hand, although girls enroll in high school biology and environmental science in greater numbers than boys, they enroll less often in calculus, physics, chemistry, and computer science (Hill, Corbett, & St. Rose, 2010, p. 6).

Unfortunately, the racial achievement gap in math and science has not closed. On the 2007 National Assessment of Educational Progress (NAEP), the scores of minority high school students continued to lag behind those of Whites and Asians (Committee on Equal Opportunities in Science & Engineering, 2009). In addition, African American and Hispanic youth have less access to Advanced Placement courses that can give students an edge in STEM. From 1990–2009, 41.2% of Asian/Pacific Islanders and 16.0% of White students took Advanced Placement/International Baccalaureate calculus classes, compared to 6.5% of African American and 9.4% of Hispanic students (NSF, 2012, Table Apx 1-8). Nevertheless, as shown later, the proportion of engineering degrees earned by minority males is comparable to, or slightly higher than, the proportion of undergraduate degrees they earn.

After (or during) high school, many students take courses at two-year community colleges. This pathway is more likely to include members of populations underrepresented in engineering and the sciences (Malcom & Malcom, 2011; NSF, 2011). Tsapogas (2004) found that between 45% and 51% of African Americans, Latinos, and Native Americans who completed four-year degrees in these fields first attended community colleges.

Research has shown that the transition from a two-year to a four-year institution is a critical juncture along the STEM pathway. Many students switch from STEM to non-STEM majors or leave higher education altogether. The evidence suggests that these outcomes have less to do with academic preparation than with the shift from a supportive to a competitive academic environment, a lack of effective advising, and feelings of isolation (Johnson & Sheppard, 2004; Packard, Gagnon, LaBelle, Jeffers, & Lynn, 2011; Reyes, 2011; Townsend, 2007; Valenzuela, 2006).

Representation by Race and Gender at the Undergraduate Level

When we disaggregate the data by gender and race, we find that women make up a smaller proportion of students earning engineering degrees than of students earning bachelor's degrees overall. The differential between men's and women's degree attainment in engineering is greatest among Whites, but the pattern holds for all racial and ethnic groups. In 2009, 1.3% of women who earned bachelor's degrees completed a B.S. in engineering, compared to 8.2% of men. Majority men (White and Asian) completed undergraduate engineering degrees at six times the rate of majority women, and minority men (African American, Hispanic, and Native American) completed such degrees at five times the rate of minority women. Figures 16.4 and 16.5 show the percentages of all B.S. degrees, B.S. degrees in engineering and science, and B.S. degrees in engineering earned by women and men, respectively.

The proportion of undergraduate engineering degrees earned by minority men is comparable to the proportion of bachelor's degrees earned by minorities overall; yet, like minority women, they are extremely underrepresented in higher education relative to their proportions in the general population. For example, U.S. Census Bureau (2008) figures show that Hispanic men comprised approximately 15% of twenty- to twenty-four-year-olds in the U.S. and that African American men comprised approximately 5% of twenty- to twenty-four-year-olds, yet Hispanic and African American men each earned less than 3.5% of all bachelor's degrees in 2009 (also see National Research Council and National Academy of Engineering, 2012).[6]

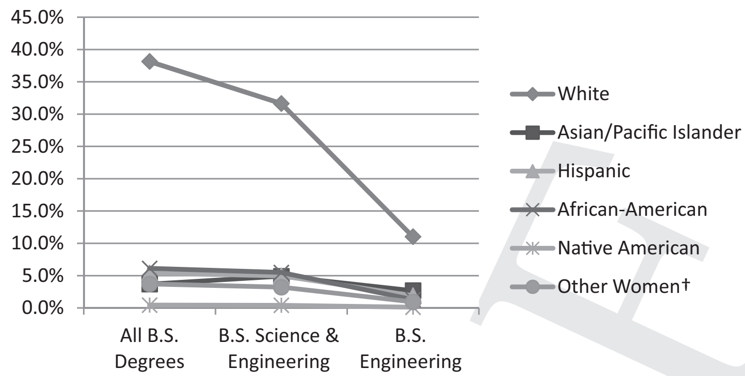

Figure 16.4. Undergraduate degrees, by race, earned by women, shown as a proportion of total degrees earned by all men and women (2009). (*Source*: National Science Foundation (2011). *Women, Minorities, and Persons with Disabilities in Science and Engineering: 2011*. Special Report NSF11–309. Division of Science Resources Statistics. Updated January 2012. Tables 5-3 & 5-4. Arlington, VA. Retrieved from http://www.nsf.gov/statistics/wmpd/). †Includes those who reported mixed race and "Unknown."

Postgraduate and Workforce Pathways

NSF is especially interested in producing highly qualified, domestically prepared, science and engineering Ph.D.s (Committee on Prospering in the Global Economy of the 21st Century, 2007). Yet doctoral engineering degrees conferred on U.S. citizens declined 21% in 2009 compared to 2000 (National Science Foundation, 2011).

Beyond the undergraduate level, White and Asian men comprise an increased proportion of engineering graduate students and professionals, but the proportions of women

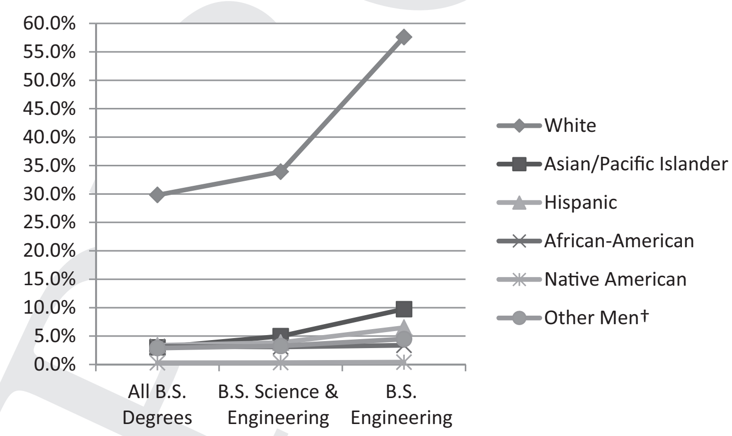

Figure 16.5. Undergraduate degrees, by race, earned by men, shown as a proportion of total degrees earned by all men and women (2009) (*Source*: National Science Foundation (2011). *Women, Minorities, and Persons with Disabilities in Science and Engineering: 2011*. Special Report NSF11–309. Division of Science Resources Statistics. Updated January 2012. Tables 5-3 & 5-4. Arlington, VA. Retrieved from http://www.nsf.gov/statistics/wmpd/). †Includes those who reported mixed race and "Unknown."

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Table 16.1. The Engineering Pathway by Race and Gender from Ph.D. to Tenure-track Positions and the Workforce[a]

	Engineering Ph.D.s (2009)[a] (%) N = 3,376		*Tenure Track Engineering Positions (2008)[a] (%) N = 18,050*		*Engineering Workforce (2006)[a] (%) N (est.) = 1,590,000*	
Race	*Female*	*Male*	*Female*	*Male*	*Female*	*Male*
White	15.6	50.6	6.1	59.8	7.5	68.7
Asian	4.1	10.9	3.3	21.1	2.3	12.5
Hispanic	1.1	3.4	0.3	2.8	0.9	4.7
African American	1.3	2.8	0.3	2.8	0.7	2.5
Native American/ Alaskan Native	0.2	0.4	0.6	0.6	0.1	0.2
Other[b]	3.1	6.5	1.2	1.4	±[c]	±[c]
Total	100	100	100			

[a] National Science Foundation, 2011, updated January, 2012. Tables 7-2, 9-26, 9-7. Each column reflects most recent data available. Comparisons across columns are for illustrative purposes only, though changes between 2008 and 2009 were negligible.
[b] Includes those who reported mixed race and "Unknown." In 2009, NSF began tracking numbers of Hawaiians and Pacific Islanders in the Tenure Track category. Those numbers (0.6% for men and women) were placed in the "Other" categories to enable comparison across years.
[c] "Other" not reported.

and minorities drop sharply. Although engineering doctorates awarded to women and minorities have increased over the past thirty years, overall numbers remain low (Cosentino de Cohen & Deterding, 2009). For example, Malcom and Malcom (2011) report that in 1975, no underrepresented minority women earned engineering doctorates (p. 167). In 2009, eighty-eight engineering Ph.D.s were awarded to underrepresented minority women (see Table 16.1).

Table 16.1 shows the representation of men and women, by race, at different points along the graduate and postgraduate STEM pathway. In 2009, of 3,376 engineering Ph.D.s awarded nationally to U.S. citizens, 804 (25.4%) were earned by women; 11% of those women (approximately 2.6% of total doctorate recipients) were underrepresented minorities. African American, Hispanic, and Native American men, combined, earned 223 (6.6%) of the engineering Ph.D.s conferred in that year (NSF, 2011).[7] Similarly, very few women and minorities take the pathway to tenure-track faculty positions in engineering. According to NSF's estimate, there were 18,050 such positions at four-year institutions in 2008. Of these, 80.9% were held by White (59.8%) and Asian (21.1%) men. African American and Hispanic men each held 2.8% of these positions, while White and Asian women held 6.1% and 3.3%, respectively. There were too few African American, Hispanic, and Native American women to be reported (NSF, 2011).[8]

The research shows one further difference in the outcomes between men and women. For the most part, the proportion of male science and engineering Ph.D.s is similar to the proportion of male faculty members and STEM workforce participants. (Asian men are an exception: their representation among tenure-track faculty is nearly twice their representation among doctorate holders.) On the other hand, the proportion of female faculty members is half or a third the proportion of females among all doctorate holders (see Table 16.1).

Even though enrollment rates for women in doctoral engineering programs are extremely low, their completion rates are as high as or higher than the rates for men.

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Nevertheless, relatively few women who earn the doctorate continue on the engineering pathway (AAAS, 2010; Committee on Women in Science and Engineering, 1994; Hosoi & Canetto, 2011). Women of all races combined comprise less than 12% of all tenure-track engineering faculty members and workforce employees. Yet studies confirm that women who do pursue tenure-track positions fare well in the interview and hiring process, and perform comparably to men on indicators of success, even achieving tenure at higher rates than men do (Committee on Gender Differences in Careers of Science, Engineering, and Mathematics Faculty, 2010).

In fact, studies suggest that gender is not a strong predictor of doctorate completion, tenure-track position seeking, or participation in the workforce (Hosoi & Canetto, 2011; Preston, 2004, 2006). Long (2001) found that marital status and childrearing responsibilities were the strongest predictors of science and engineering labor force participation, for both men and women, but differentially. Although single men and women were found to participate in the workforce at similar rates, being married and having young children predicted *increased* rates of engineering employment for men and *decreased* rates of engineering employment for women.

Among women who choose the engineering pathway, we see retention rates at each level of education that are comparable to and sometimes higher than those of men. However, we also see dramatic rates of decline in persistence across each juncture along the engineering pathway (Chubin, May, & Babco, 2005). Women who have succeeded at one level of preparation in engineering often opt out of further engineering study or out of the profession (Fouad, Fitzpatrick, & Liu, 2011).

Retention Within Each Phase Along the STEM Pathway

Recent research indicates that students in undergraduate engineering programs at four-year institutions have retention rates similar to or higher than those of students in other majors (George-Jackson, 2011; Lord et al., 2009; McCormick, Lichtenstein, Chen, Puma, & Sheppard, manuscript submitted for publication; Ohland et al., 2008). At all academic levels, underrepresented minorities and women remain in engineering programs at rates comparable to those of White and Asian men (Cosentino de Cohen & Deterding, 2009; Hosoi & Canetto, 2011).

These findings, although pervasive, are typically based on longitudinal studies whose data sources cannot capture students if they move from one institution to another, or if they leave higher education altogether. Some research suggests that minority students who transfer from a two-year to a four-year institution struggle disproportionately when they encounter a competitive environment, and that they experience feelings of social and cultural isolation when they are no longer surrounded by peers of the same race or ethnicity (Crawford & Macleod, 1990; Hagedorn, Maxwell, Cypers, Hye Sun, & Lester, 2007; Russell & Atwater, 2005; Townsend, 2007).

Moreover, retention is a negative outcome when students remain on pathways that do not lead to degree completion. Chen and Weko (2009) found that engineering had the highest proportion of students (19.3%) persisting in their major without earning a degree after six years. Hurtado et al. (2010) looked at degree completion rates among 201,588 students in 326 four-year institutions. The authors found that minorities and non-minorities have comparable rates of retention in STEM majors, but minorities in STEM have significantly lower rates of degree completion – the five-year degree completion rates for Asians (42%) and Whites (33%) are nearly twice those of Latinos (22%), African Americans (18%), and Native Americans (19%).

Yet discerning completion rates can be complicated. Ohland et al. (2011) found notable differences in the patterns of undergraduate degree completion by race, based on institutional differences. Although some

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factors were consistent by race, analyses that did not factor in institutional policies and program structures distorted completion rates.

Retention rates are comparable among STEM students regardless of ethnicity, and retention in degree programs among women tends to be higher than that of White and Asian men. But the conditions under which women and minorities study differ from those experienced by majority men, and these conditions can affect their completion rates. Faced with unsupportive institutional policies and negative classroom environments, women and underrepresented minorities consistently report experiences of isolation, self-doubt, and questioning about continuing in engineering programs and post-degree work settings. This phenomenon is described throughout the research literature as *chilly climate* (Hall & Sandler, 1982, 1984; Johnson & Lucero, 2003; Morris & Daniel, 2008; Sandler, Silverberg, & Hall, 1996).

Chilly climate results from several conditions that have been consistently documented in the research literature for decades, including negative interpersonal relations, subtle and overt denigration of skills, attribution of attainment to affirmative action policies, avoidance of eye contact, favoritism toward male and majority students, sexual harassment, and, in the workplace, a dearth of opportunities to advance, failure to be recognized for contributions, and wage disparities (CEOSE, 2009; Crawford & MacLeod, 1990; Daempfle, 2003; Miner-Rubino & Cortina, 2004; Malcom & Malcom, 2011; National Academy of Sciences, 2007; Seymour & Hewitt, 1997; Wyer, 2003). Brown (2000) found chilly climate to be a more challenging issue for women and people of color in academia than lack of financial support, recruitment practices, or composition of faculty. Chilly climate is rarely reported by White and Asian men, who comprise the majority of engineering students and workforce employees. But it is commonly mentioned in interviews with minorities and women, and it has been cited as a common cause of attrition from all levels of engineering education and from the workforce.

Other barriers also impede the progress of women and underrepresented minorities in engineering, both during and after degree completion. For undergraduates, these may include an absence of role models, limited interaction with faculty, and a lack of effective advising (Johnson & Sheppard, 2004; Seymour & Hewitt, 1997; Tsui, 2010). For graduate students and early-career faculty, a lack of role models and mentors is an especially critical factor (Davidson & Foster-Johnson, 2001; Office of Scientific and Engineering Personnel, 1994; Nelson & Rogers, 2007; Reybold & Alamia, 2008). In the workplace, common barriers include lack of mentoring and lack of support in balancing work/family tensions (Fouad et al., 2011; Miner-Rubino & Cortina, 2004; Preston, 2004, 2006).

Lack of financial aid is also cited as a barrier to minorities' attainment of STEM degrees (Chubin et al., 2005; Clewell & Tinto, 1999). Studies consistently show that financial aid is a predictor of college retention among minorities (Carter, 2006; Georges, 1999; Lee, 1991). Recent research finds that financial aid increasingly takes the form of loans as opposed to grants and scholarships, and increasingly fails to keep pace with the rising costs of higher education (Lee & Clery, 2004; NRC, 2007). Among the obstacles to degree completion, lack of financial aid is cited less often than chilly climate, lack of faculty contact and mentors, and work/family tensions. Even so, in an era of high unemployment and housing market declines, all of which disproportionately affect minorities and women, cutbacks in grant and scholarship programs could have an increasingly significant impact on retention in engineering specifically and in STEM more generally (Joint Economic Committee, 2011; Kochhar, 2011; Kochhar, Fry, & Taylor, 2011).

Family circumstances are commonly cited by women and minorities as influencing their retention in STEM. Ong et al. (2011) conclude, "Family and community support

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is perhaps the most salient and influential factor that women of color identify as encouraging to their completion of a STEM degree" (p. 186). Fouad et al. (2011) conducted a qualitative study of female engineers, fourteen of whom were currently practicing and eleven of whom had left the field. The authors identified five domains in which these women encountered challenges, including *support and/or barriers in work and family*. Women who had left engineering cited among their reasons the need to care for their children, in addition to issues specific to the workplace environment, including lack of movement into management roles and a dislike of engineering tasks or environment. Women who remained in engineering also mentioned family responsibilities as challenges. Valenzuela (2006) examined the impact of family support on Latina transfer students. Russell and Atwater (2005) documented the importance of family support to African American undergraduates at a predominantly White university. Bellisari (1991) found that Asian and African American women's choice of and retention in science majors were strongly influenced by family expectations. Moller-Wong and Eide (1997) found that marital status (being married) was a high-risk factor related to retention in the engineering major.

Trenor, Yu, Waight, Zerda, and Sha (2008), in their mixed-methods study of ethnically diverse female engineering students, found that motivations for pursuing engineering varied for different ethnic groups. Li, Swaminathan, and Tang (2009) reviewed internal and external factors that predict success in engineering, including community and college influence (external characteristics), cognitive and affective characteristics (internal), and demographic variables. Their findings highlight a need for more sophisticated measurement approaches that can model the interaction effects among these various factors on educational outcomes. Besterfield-Sacre, Atman, and Shuman (1998) and Besterfield, Moreno, Shuman, and Atman (2001) found that African American and Hispanic students exhibit more positive impressions of engineers than do White students or members of other ethnic minorities (e.g., Asian-Pacific Islanders). Yet the self-efficacy of African American and Hispanic students was found to decrease during the freshman year (Besterfield-Sacre et al., 1998, 2001). Why is this so? The evidence is overwhelming that, for both minorities and women, environmental factors play a decisive role in limiting retention and persistence in engineering.

Promoting Retention and Persistence in STEM: What the Research Tells Us

Several studies and policy documents indicate that increased diversity in the classroom and workplace enhances scholarship, achievement, and productivity in general (AAAS, 2010; Gurin, Dey, Hurtado, & Gurin, 2002; Page, 2008; Satcher, 2001). Although it has proven difficult to raise persistence rates of women and underrepresented minorities in engineering and the sciences, successes have been documented. Furthermore, research has identified strategies that consistently promote recruitment and persistence in K–12 and higher education institutions and workplaces. Concerted attempts to improve academic and workplace climates and to boost recruitment of minorities and women have yielded encouraging results (see Tinto, 1993; Hill, Corbett, & St. Rose, 2010). The research suggests that effective policies and practices respond to a broad range of student needs and benefit all students, not just women and underrepresented minorities. In this section, we begin with classroom strategies and then consider strategies implemented at the institutional level.

Research-Based Strategies for Improving Classroom Climate

Learner-centered pedagogical approaches have proven effective in engaging diverse student populations. Amelink and Creamer

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(2010) highlight the impact of peer interactions on academic and professional persistence. Not surprisingly, the extent to which women students feel respected as classmates can influence their assessment of their own engineering abilities and their emerging identities as prospective engineers. Seeking a better understanding of engineering student achievement and career plans, Jones, Paretti, Hein, and Knott (2010) differentiated between *expectancy-related constructs* (i.e., engineering self-efficacy and expectations to succeed in engineering) and *value-related constructs* (i.e., engineering identity and beliefs about the importance and usefulness of engineering). Findings from a survey of 363 first-year engineering students showed that expectancy-related constructs tended to predict achievement and that value-related constructs predicted career plans in engineering for both men and women.

In addition to peer interactions, faculty–student interactions play a significant role in forming engineering identities and subsequent career decision making, leading to greater student satisfaction and undergraduate persistence in engineering (Lattuca, Terenzini, & Volkwein, 2006; Pascarella & Terenzini, 2005). Faculty–student interactions both inside and outside the classroom have been shown to influence the career goals of female students (Amelink & Creamer, 2010; Bernold, 2007; Braxton, Milem, & Sullivan, 2000; Eskandari et al., 2007; Springer, Stanne, & Donovan, 1997; Terenzini, Cabrera, Colbeck, Parente, & Bjorklund, 2001). Particularly for minority students, positive interactions with engineering faculty role models can have a significant influence on students' decisions to pursue graduate study in engineering (May & Chubin, 2003; Tinto, 1975). Positive faculty–student interactions contribute to greater student retention and academic success by enhancing engineering students' confidence in their problem-solving, engineering design, and professional and interpersonal skills (Bjorklund, Parente, & Sathianathan, 2004; Chen, Lattuca, & Hamilton, 2008). Chen et al. (2008) emphasize that faculty promote student engagement in engineering by helping students understand the importance of developing professional and interpersonal skills, providing undergraduate research experiences, and encouraging academic achievement.

In recent years, *pedagogies of engagement*, including cooperative learning, problem-based and project-based learning, case-based learning, and service learning, have garnered increasing interest by engineering faculty (Smith, 2011; Smith, Sheppard, Johnson, & Johnson, 2005; Vaughn & Seifer, 2004). Pedagogies of engagement, which are characterized by small groups of students working together to solve meaningful problems, have been shown through research to promote academic learning and social integration, both of which are critical for retention of all students in college. McKeachie, Pintrich, Yi-Guang, and Smith (1986) found that learning how to engage in critical thinking depends on student participation in class, teacher encouragement, and student-to-student interaction. Tinto (2002, p. 2) identifies five essential conditions for student learning and retention in college: (1) being held to high expectations, (2) receiving academic and social support, (3) receiving feedback about performance, (4) academic and social integration, and (5) relevant learning. Pedagogies of engagement contribute to establishing these conditions.

Cooperative learning is probably the most thoroughly researched pedagogy of engagement. There are currently more than 400 articles on cooperative learning in STEM disciplines, including several meta-analyses (Johnson, Johnson, & Smith, 2006; Smith, Sheppard, Johnson, & Johnson, 2005). First introduced to the engineering education community more than thirty years ago (Smith, Johnson, & Johnson, 1981), cooperative learning has demonstrated its efficacy in promoting student learning and a positive classroom environment. Research has focused primarily on student achievement, but there are studies related to student persistence and retention as well.

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The conceptual framework underlying cooperative learning (Deutsch 1949, 1962) addresses issues pertinent to the educational experiences of women and underrepresented minorities, who often report finding traditional classroom environments "chilly," "aggressive," and inimical to diverse learning styles (Crawford & McLeod, 1990). Balancing challenging material with support for learning has been identified as an important factor in (1) promoting high-level performance among all students and (2) improving retention and persistence among women and underrepresented minorities alienated by competitive classroom structures (Edmonson, 2008; Pelz & Andrews, 1966). A 1997 meta-analysis of cooperative learning in introductory-level STEM classes showed moderate to high mean effect sizes for achievement, persistence, and attitudes: 0.51, 0.46, and 0.55, respectively (Springer, Stanne, & Donovan, 1999).

Johnson et al. (2006) found through their meta-analysis of twenty-four studies that cooperative efforts promoted greater liking among students than did competition (effect size = 0.68) or independent work (effect size = 0.55). College students learning cooperatively perceived more academic and personal support from peers and instructors than did students working competitively (effect size = 0.60) or individualistically (effect size = 0.51). Extensive research indicates that the benefits of cooperation are felt among all students, regardless of race and culture, language, social class, ability, and gender (Johnson & Johnson, 1989). Cooperative learning is one example of an evidence-based practice within the family of pedagogies of engagement that promotes learning and retention among all students, and warms chilly classroom environments.

Warming Chilly Climates in Higher Education and Workplaces

There is a growing body of evidence concerning successful efforts on the institutional level to recruit and retain women and minorities, both in academia and in the STEM workforce. The National Academy of Engineering's Center for the Advancement of Scholarship in Engineering Education (CASEE) includes on its website a list of research-based programs that have proven effective in increasing student retention and persistence. Although these programs focus on women, the criteria for inclusion on the list include demonstrated efficacy for multiple demographic groups (National Academy of Engineering, 2012).

The research literature consistently refers to several strategies that have effectively promoted retention and persistence among STEM undergraduates, graduate students, faculty, and members of the workforce. These strategies include providing hands-on undergraduate and graduate research experiences, aligning new programs with successful existing ones, extending the "personal touch" with plenty of mentoring and attention to individual needs, providing incentives to laboratory researchers to broaden participation by women and underrepresented minorities, and having personnel dedicated to tracking students in academic programs (CEOSE, 2009; French, Immekus, & Oakes, 2005).

"High-impact practices" such as first-year seminars, capstone projects, and learning communities benefit students from diverse backgrounds, increasing rates of retention and engagement and supporting student persistence (Kuh, 2008; Kuh et al., 2005; Pascarella & Terenzini, 2005; Terenzini et al., 2001). These practices promote student interactions with faculty and peers around meaningful questions and issues, thereby deepening students' investments in these activities as well as their commitment to the academic program and the institution as a whole. Internships that provide candidates with work experience in industry can be important for building professional networks that increase affiliation with engineering and thereby encourage persistence (Ong et al., 2011).

Muraskin, Lee, Wilner, and Swail (2004) compared undergraduate institutions with higher and lower completion rates for low-income students. Those with Higher Graduate Rates (HGR) tended to attract more

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students who had recently finished high school and who were better prepared academically. HGR institutions had more full-time faculty, lower student/faculty ratios, and greater financial subsidies than did Low Graduate Rate (LGR) institutions. HGR colleges and universities shared several institutional policies and practices, including small class sizes, careful academic planning for students, special programs for students at academic risk, programs to promote a sense of belonging to the campus community, extensive academic support services, accessible faculty, modest selectivity, and initiatives aimed at promoting retention and high graduation rates.

Fox, Sonnert, and Nikiforova (2009) conducted a mixed-methods study examining forty-nine programs designed to support women undergraduates in the sciences and engineering. The authors began with a regression analysis, using numbers of women graduating from these programs between 1984 and 2001 as a dependent variable. Then they interviewed the directors of the ten most successful and the ten least successful programs. The authors found that leaders of successful programs had a well-elaborated understanding of issues related to recruitment and retention within their institutions, promoted a range of strategies, actively linked students with resources, and integrated their services with other university programs.

Tsui (2010) conducted 110 interviews and 25 focus groups with mechanical engineering faculty, staff, and senior undergraduates at six universities nationally. She found that access to women- or minority-focused organizations (e.g., Society of Women Engineers, National Society of Black Engineers, Hispanic Engineering & Science Organization) helped dispel students' feelings of isolation. Participation in other student organizations, especially those with a humanitarian or community focus, as well as participation in regional and national conferences, helped women and minorities affiliate with the engineering profession and find mentors and role models. Students who enrolled early in an engineering department demonstrated higher degree commitment and sense of belonging than did students who spent the first two years taking non-engineering courses from non-engineering departments.

In a comprehensive synthesis of literature on undergraduate and graduate women of color in STEM fields, Ong et al. (2011) showed that role models and mentors are especially important to the success of women, particularly women of color, in doctoral programs. Mentoring by faculty, the authors wrote, "was rare but incredibly valuable" (p. 193). The authors found that mentors need not be of the same gender or ethnicity as those they mentor. Brown (2000) found that "few minority women had true mentors while in graduate school, but those who did reported exceptional relationships and experiences" (p. 259). Mentors can play important roles in students' decisions to attend graduate school, choose a particular doctoral program, or remain in their programs.

Fouad et al. (2011) surveyed more than 3,700 women who graduated with engineering degrees. They analyzed factors that predicted women's decisions to remain in the engineering workforce. Perceptions of workplace climate, the presence or absence of support from colleagues and supervisors, and the availability of opportunities for advancement influenced career decision-making. Women were more likely to remain when company policies and practices supported the challenges of balancing multiple life roles. Yet women who left engineering did not attribute their decisions to their childrearing responsibilities. Women who left engineering jobs tended to leave the engineering profession entirely.

Summary and Future Research

Summary

In spite of a federal policy imperative to expand the engineering workforce, the

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proportion of college and university students pursuing engineering degrees continues to decline (President's Council on Jobs and Competitiveness, 2011). And in spite of a policy agenda targeted at boosting participation of women and underrepresented minorities in the engineering workforce, progress has been slow.

Research over the past several decades has consistently identified factors that reduce participation of women and underrepresented minorities within and between phases of the engineering pathway, including competitive classroom pedagogies, inadequate advising, lack of mentors and role models, discrimination and bias, limited access to financial aid, and lack of attention to and accommodation of family issues. Several of these factors have been associated with *chilly climate* (Hall & Sandler, 1982), an inhospitable environment that has been documented in the in postsecondary classrooms, higher education workplaces, and in business work environments.

On the other hand, research has also identified policies and practices that overcome these obstacles. Strategies include pedagogies of engagement at the classroom level and policies and practices within academic institutions and work environments that (1) promote students' affiliation with their department and the institution overall, and (2) help students and employees balance academic and professional advancement with family responsibilities. These pedagogies, policies, and practices benefit all engineering candidates and working engineers, not just women and underrepresented minorities.

Areas for Further Research

Understanding the interplay of factors contributing to recruitment, retention, and persistence in engineering, especially among women and underrepresented minorities, requires the application of a range of academic disciplines, including psychology, education, economics, and sociology as well as engineering. Engineering educators, who hail from a variety of disciplines, are well situated to tackle this critical issue.

Research and policy documents related to the supply of engineers are extensive. But the demand for engineers has received little attention (see, however, Carnevale, Smith, & Melton, 2011). The field would benefit from studies into the need for domestically trained engineers, including what kinds of engineers are in greatest demand across various industries.

In preparing this review, the authors found more literature pertaining directly to women than to minorities, although there is crossover in many articles. The field would benefit from more research on underrepresented minorities, including African Americans, Hispanics, Native Americans, and Asian subgroups consisting largely of first- or second-generation immigrants (see Ngo, 2006). Because participation patterns vary significantly between men and women within these groups, studies should disaggregate by gender.

We need a refined understanding of the circumstances that influence women and underrepresented minorities at critical decision-making junctures. Namely, as they decide whether to study engineering in the first place, and then whether to continue along each point of the engineering pathway. Why do so few women and minority undergraduates choose to major in engineering? Why do we lose so many women between junctures? How do family circumstances, including marital status, childrearing responsibilities, and cultural expectations, affect decisions to participate in engineering at every step along the way? There are several studies of students who chose engineering and the factors that influenced their persistence (see, e.g., Fouad et al.+, 2011; Lichtenstein, Loshbaugh, Claar, Bailey, & Sheppard, 2007; Lichtenstein et al., 2009; Russell & Atwater, 2005; Valenzuela, 2006). Yet qualitative research concerning those who did not choose engineering is scant.

Higher education would benefit from studies tracing the differential effects of institutional policies (e.g., transfer policies, structure of majors, workload) on various student populations (Lichtenstein, McCormick, Puma, & Sheppard, 2010). Longitudinal student studies, both quantitative and qualitative, that can reach across institutional boundaries will be necessary to further our understanding of how women and underrepresented minorities negotiate the engineering pathway, especially because many of these students transfer from two-year to four-year institutions. Greater attention could be paid to this pathway (see National Research Council and National Academy of Engineering, 2012).

To date, much of the research into retention and persistence has been correlational (Johnson, 2011). Studies that draw causal relationships between specific policies, practices, and conditions and how those impact participation in STEM fields will be essential for identifying strategies that can increase the representation of women and minorities in these fields.

In this chapter, we have reviewed strategies that have been proven to promote retention and persistence of all students in engineering, and of women and underrepresented minorities in particular. But how do we get colleges and universities to adopt these strategies? The incentive structures and institutional cultures of higher education are notoriously intractable and carry with them the tensile memory of steel. Colleges and universities have struggled to translate research findings into sustainable policies, programs, and practices. Yet, in many cases where faculty and administrators – individually and/or collectively – were sufficiently committed to reform, these obstacles have been overcome (see, e.g., O'Meara, 2012). An emerging literature on the diffusion of innovation in engineering education is directly relevant to issues of retention and persistence (see Chapter 19 by Litzinger & Lattuca, this volume). Lessons from this literature hold promise for supporting all students on STEM pathways, as well as addressing issues of retention and persistence that for decades have limited the participation of women and underrepresented minorities in engineering.

Acknowledgments

The authors are grateful to Arthur Evenchik for his exceptional editorial support, and to Dr. Sheri Sheppard, Dr. Stephanie Adams, and CHEER reviewers for their thoughtful suggestions. We are also grateful to Ms. Susan Olmsted, National Science Foundation reference librarian, for her invaluable assistance.

Footnotes

1. Data were not available concerning ethnic minority employment in these countries.
2. In the 1970s, "minorities" referred to non-Whites generally. Among minorities, African Americans were better organized than other ethnic groups, largely because of the civil rights movement, and therefore African American voices were heard more often in testimony to Congress and in other political arenas. Yet "minorities" also included Hispanics, Native Americans, and Asians. By the 1990s, the term "underrepresented minorities" emerged. This category typically excludes Japanese and Chinese Americans, who are overrepresented in higher education in comparison to their numbers in the general population. The terms "minority" and "underrepresented minority" refer to U.S. citizens and do not include international students.
3. Science and Engineering Equal Opportunities Act, Section 32(b), Part B of P.L. 96–516, 94 Stat. 3010, as amended by P.L. 99–159.
4. The Science and Technology Equal Opportunity Act requires NSF to submit a report to Congress every two years detailing its activities and progress in expanding the talent pool in science and engineering among minorities and women (in recent years, the charge has expanded to include people with disabilities). The standing committee charged with this task, the Committee on Equal Opportunities in Science & Engineering (CEOSE), was chaired by Dr. Theresa Maldonado, one of this chapter's co-authors, in 2009–2010.

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5. Interestingly, all of the science and engineering workforce forecasts since the 1950s have calculated only the supply side, not the demand side of the equation.
6. See U.S. Census Bureau, Age & Sex in the United States, 2008: http://www.census.gov/population/www/socdemo/age/age_sex_2008.html).
7. The proportion of foreign students earning doctoral degrees in engineering has increased. In 2009, foreign nationals accounted for 55% of all engineering Ph.D.s conferred in the United States, up from 49.9% in 2000 (Brown, 2000; Gibbons, 2009). Statistics for foreign nationals are not included in this chapter.
8. NSF does not include counts when estimates are less than 50 because a count might compromise confidentiality. The relevant data table, Table 9-26, shows science and engineering doctorate holders employed in universities and four-year colleges, classified by field, sex, race/ethnicity, and tenure status. Six cells within engineering contained "D"s, indicating a count smaller than 50. For current purposes, "D"s were treated as 50, overestimating the number of tenured and tenure-track positions and the numbers of faculty members who hold them.

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