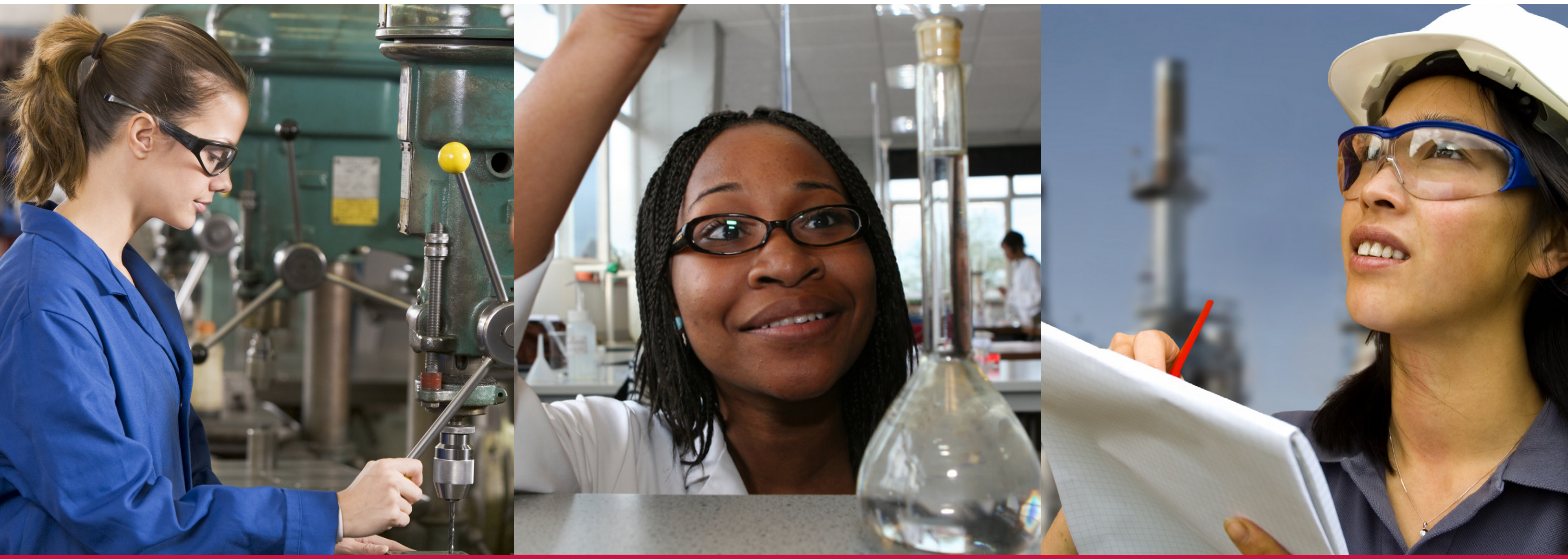
Pedagogical Methods for Improving Women's Participation and Success in Engineering Education

A Review of Recent Literature



Institute for Women's Policy Research

About This Report

The research presented in this report was conducted by the Institute for Women's Policy Research for the Engineering Equity Extension Service (EEES) of the National Academy of Engineering's Center for the Advancement of Scholarship on Engineering Education (CASEE). The EEES seeks to increase women's completion of undergraduate engineering degrees by offering technical assistance, training, and supportive networks. This report is part of a series of occasional IWPR research on women's opportunities and outcomes in key industries.

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The Institute for Women's Policy Research (IWPR) conducts rigorous research and disseminates its findings to address the needs of women, promote public dialogue, and strengthen families, communities, and societies. IWPR focuses on issues of poverty and welfare, employment and earnings, work and family, health and safety, and women's civic and political participation.

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Institute for Women's Policy Research
1707 L Street NW, Suite 750
Washington, DC 20036
Phone: (202) 785 5100 Fax: (202) 833 4362
www.iwpr.org

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Pedagogical Methods for Improving Women's Participation and Success in Engineering Education

A Review of Recent Literature*

By Lynette Osborne, Ph.D., Kevin Miller, Ph.D., and Robin Farabee-Siers

INSTITUTE FOR WOMEN'S POLICY RESEARCH
1707 L Street NW, Suite 750 • Washington, DC 20036
202 785 5100 • www.iwpr.org

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Introduction

The field of engineering has been slow to open to women. While women received 55 percent of social science Bachelor's degrees and 62 percent of biological science Bachelor's degrees awarded in 2003, only 20 percent of engineering Bachelor's degrees were awarded to women. The same year, women made up 43 percent of the workforce among social scientists and 43 percent among biological scientists but made up only 11 percent of the engineering workforce (National Science Foundation, 2007).

Targeted pedagogical interventions have the potential to help improve women's representation in the engineering disciplines. This Literature Review surveys recent literature that describes and assesses interventions designed to improve retention and success in undergraduate engineering education that have relevance to efforts to improve gender representation. It focuses on two main bodies of empirical work: 1) research articles that address instructional practices asserted to enhance the attraction, retention, and progression of women in engineering classes, and 2) empirical articles that assess a learning intervention in undergraduate engineering classes that could be related to how college women learn.

For each of the following sources of empirical articles, three years of contents were searched (2005 – 2008):

- Society of Women Engineers (SWE) Literature Reviews
- Journal of Engineering Education
- Journal of Women and Minorities in Science and Engineering
- Engineering Education

For the SWE Literature Reviews, all articles relating to the education of women in undergraduate engineering were identified and reviewed for pertinence in this study. For articles in the three journals identified above, each volume was reviewed either online or at a university library; articles fitting the parameters of this project were selected and assessed for inclusion in the Literature Review. A total of 281 journal articles were evaluated. (See Table 1 for the number of articles reviewed per journal.) Thirteen articles that either a) addressed instructional practices asserted to enhance the attraction, retention, and progression of undergraduate women in engineering classes or b) assessed a learning intervention in undergraduate engineering classes that could be related to how college women learn, were identified and included. In addition to the Literature Review, each article was coded according to a rubric developed by the Center for the Advancement of Engineering Education of the National Academy of Engineering for later uploading to the PR^{2}OVE-IT[1] database.[2]

Table 1. Journal articles evaluated and selected for inclusion in the literature review, by journal and year

Journal Title	2005 Articles	2006 Articles	2007 Articles	2008* Articles	Total Articles by Journal	Articles Meeting Criteria
SWE Literature Review	0	15	7	0	22	3
Journal of Engineering Education	48	39	37	38	162	7
Journal of Women and Minorities in Science and Engineering	22	20	20	5	67	2
Engineering Education	0	8	15	7	30	1
Total articles reviewed	**70**	**82**	**79**	**50**	**281**	**13**

*2008 articles reviewed were from January to June.

[1] The PR^{2}OVE-IT (Peer Reviewed Research Offering Validation of Effective and Innovative Teaching) web site is a clearinghouse that summarizes available research on educational interventions designed to enhance student learning, retention, and professional success in post-secondary engineering and other sciences. It is located at www.pr2ove-it.org.
[2] Copies of the datasheets are available from the author.

In-Class Pedagogical Interventions

The classroom environment is a particularly powerful determinant of persistence in engineering, especially for women students. Research suggests that student learning and interest in engineering are enhanced when instructors tailor class activities to match students' existing knowledge and their pace of learning, and when instructors actively engage students in learning rather than simply relying on lecturing. None of the research projects discussed in this section directly addresses gender as an issue; however, each contributes to the literature related to women's success in engineering because they utilize approaches that previous research suggests are beneficial to the retention and success of students, particularly women students, in engineering. (For background, see: Catalano and Catalano 1999; Felder 1995; Haller and Felder 1995; Nair and Majitech 1995; Riley 2003; Rosser 1999, 1989; Smith, Sheppard, Johnson, and Johnson 1995). Possible implications of these studies for women's engagement in engineering education are discussed in the section titled Relevance of Gender-Neutral Research for Women's Education*, below.*

In an effort to increase student learning in an electrical circuit course, Reisslein, Sullivan, and Reisslein (2007) studied the effect of transitioning from worked problems to problem sets. The authors contend that student learning would be positively affected by using different paces of transitioning from worked problems for students to study to having students work through the entire problems.

Reisslein et al. studied the effects of a computerized, varied-paced problem set program on 235 engineering freshmen enrolled in an electrical circuit course. Of the participants, 186 were male, and 49 were female. Based on a pre-test, the researchers divided students into groups defined by those with high, medium, or low prior knowledge in electrical engineering. Students were then randomly assigned to a treatment group of immediate transitioning (problems assigned with an overview of the information needed, but without a worked example), fast fading (four worked problems provided but with less information provided for each problem, then additional problems assigned to be solved by students), and slow fading (complete worked problems provided for the first two problems; the first two steps of problems three and four solved, with students required to complete the third solution step; only the first step shown for problems five and six; no assistance provided for the last two problems).

The authors compared pre- and post-test data to evaluate the impact of the various fading systems on student learning. According to the authors, using a tailored approach to teaching students about electrical circuit analysis provides a learning environment that allows students with differing levels of prior knowledge to learn and use skills at a pace that encourages each student's learning rather than frustrating and discouraging them. The researchers found that slow transitioning for students with little prior knowledge and fast or immediate paced transitioning for students with some prior knowledge improved learning significantly. The authors conclude that differential pacing for problem sets is associated with increased learning. They also note that incorporating this type of learning approach can be accomplished through a variety of means (e.g., worksheets, workbooks, blackboard) aside from the computer-assisted problem sets used in their study, which may make it more feasible for instructors who have limited financial resources.

Roselli and Brophy (2006) report on a study geared toward assessing the effectiveness of challenge-based instruction (CBI) as compared to lecture-based instruction in biomechanics courses. Building on the Problem-Based Learning model, CBI has three key characteristics: provides students with challenges that set the stage for increased knowledge and that increase their ability to use the knowledge in applied situations; it continually encourages students to test their knowledge in different ways; and it gives students opportunities to "refine what they know and reapply this knowledge to a variety of contexts" (p. 312). Students are provided with challenges throughout an academic term that are based on real-life problems. Students are given the opportunity to build on known concepts while learning and applying new ones to solve the challenges.

Assuming that students in a CBI course would have more in-class time to devote to asking questions and gaining clarification of difficult concepts since the instructional approach emphasizes more discussion than the lecture-based sections, the researchers hypothesized that students in the CBI class would outperform those in lecture-based courses. Student grades for two introductory biomechanics courses were evaluated (courses were taught by different instructors, one using a more traditional lecture-based format, and the other using the CBI approach). The researchers triangulated classroom observations, survey data of student perceptions of "how well the course was informed by the HPL framework and their reactions to various methods used during the semester" (p. 315), and final exam questions.

From the triangulated data, the researchers report that students in CBI courses perform as well or better than students in lecture-based courses. In fact, they found that students who participated in the CBI scored better on some of the more difficult knowledge-based questions from their final exams than those students in lecture classes. Roselli and Brophy conclude that overall, the students exposed to CBI benefited from the pedagogical approach that required active engagement with the course material. They argue that this active engagement allows students to develop a deeper understanding of the topics, including particularly difficult concepts such as moments. While the authors acknowledge that the CBI method requires more and different planning on the part of instructors, and may be more demanding for students, the positive outcome of increased learning should better prepare students for the workplace and for life-long learning.

In an attempt to provide an innovative approach to students' hands-on lab experience, Read, Hanson and Levesley (2008) developed, implemented, and assessed an off-site "weblab" experience for engineering students. Acknowledging the difficulty in recruiting and retaining a diverse student base in engineering, the authors developed "short interactive experiments that can be carried out by the students at any time from anywhere" (p. 52). These weblabs were created for and used by mechanical engineering sophomore undergraduates in their course on vibration and control, and for juniors studying applied mechanics and automatic control. Weblabs allowed students to participate in web-based experiments via their school's intranet, providing them with flexibility in terms of where and when they completed the labs. Additionally, students received immediate feedback on the lab exercises and were then able to repeat labs if necessary.

The researchers used triangulation of several data-gathering techniques to assess the effects of the weblabs on student learning and satisfaction. First, each student was assigned a unique access code that allowed researchers to track how often students logged on to the program. This allowed the authors to track how much time students spent online working on labs. Second, they held discussion (focus) groups with students to acquire feedback on student perceptions of the lab delivery system. Two groups were assessed in terms of their time spent on the weblabs and their post-test scores in the courses. In addition to course instruction, the "local" group attended traditional, hands-on labs as well as using the weblab system, whereas the "distance" group used only the weblabs.

Results of the access data indicated that students returned to the experiments much more often than they needed to simply to complete the experiments. The authors surmised that students were using the system to "play" with the experiments after they had completed their assigned tasks. While increased activity may be related to novelty, the discussion groups with students revealed that students were "checking and repeating results obtained in the hands-on situation, with some using the weblab to experiment further with differing parameters" (p. 58).

Student overall scores in the course were also used to assess impact of the weblab system. Students who used only the weblab system scored as well in the courses as those who used the weblab in addition to the hands-on lab activities. The authors concluded that, overall, there was a great deal of support for the weblab system in terms of providing a unique delivery system for engineering labs. They argued that this system allows students more time and less pressure to complete engineering experiments, allowing students an opportunity to develop their skills. As an alternative delivery system, they argued that it provides a positive experience in engineering lab work that will likely serve to encourage diverse populations to remain in engineering.

In addition to applied engineering proficiency, many engineering students are also expected to learn research skills. Thompson Alford, Liao, Johnson and Matthews (2005) approached innovation in engineering education by integrating a research component into the undergraduate curriculum. The Research Communications Studio (RCS) is a teaching approach used to draw from communications and engineering in order to help students develop strong written, oral, and graphical communication skills while they advance their engineering research abilities. Engineering students meet weekly in small groups with a communications faculty member, a communications graduate student, and an engineering graduate student. Engineering faculty members serve as advisors for the courses as well. Drawing on the Boyer Commission's contention that "no idea is fully formed until it can be communicated, and … the organization required for writing and speaking is part of the thought process that enables one to understand material fully" (p. 3), the RCS uses the weekly meetings as an opportunity for structured discussion of research problems and peer (as well as faculty) discussion of strategies to address the problems.

The researchers gathered information regarding student learning from faculty advisors, graduate mentors, and undergraduate participants to assess the utility of the program. Of specific interest to the project were perceptions of faculty and graduate student mentors' perceptions of undergraduate learning, as well as the type of learning (research and/or communication) that occurred, among the undergraduates. Data collected from the Faculty Survey and Mentor Survey showed that faculty and graduate student mentors believed the participating undergraduates gained a great deal of working knowledge about the research process in engineering as well as how to effectively convey the research in written reports and oral presentations. The participants (students, faculty, and graduate mentors) rated the experience highly in terms of satisfaction. The authors argue that the novel RCS approach for integrating research into engineering using a small-group environment provided students with a successful means through which to acquire engineering research skills. They also note that faculty members also indicated that the undergraduates "were able to think scientifically, understand scientific research, synthesize information from diverse sources, and take more initiative in framing and solving research problems" (p. 305) as a result of participating in the RCS. Overall, the authors contend that the program is an effective way to teach undergraduates about research in a novel, engaging manner.

Faculty Impact

In-class innovations are only one way to approach understanding and increasing student achievement in engineering. In this section, two articles related to faculty impact on student success are reviewed. Specifically, they assess the effects of a faculty development program on student success and retention and the impact of faculty distance to student self-efficacy and self-confidence.

In an effort to better understand the relationship between student retention and achievement and faculty attitudes, McShannon, Hynes, Nirmalakhandan, Venkataramana, Ricketts, Ulery and Steiner (2006) studied the faculty development program Gaining Retention and Achievement for Students Program (GRASP). This brief report highlights the faculty development component of the GRASP program that focused on undergraduates' retention and achievement. As faculty members are critical to student retention, this part of the program emphasized modifying teaching techniques, moving from primarily lecture to approaches that integrate activities that are associated with student retention and achievement.

Fifty-three STEM faculty members participated in the GRASP program between spring 1999 and spring 2004. The authors assessed student achievement by comparing "students enrolled in the courses faculty were teaching during GRASP, to students enrolled in the same course taught by the same faculty before they had participated in GRASP" (p. 206). In all, grades from 1,658 pre-GRASP course students were compared to those of 1,854 students enrolled in GRASP courses. The researchers report an average difference of 5.6 percent between the pre-GRASP student grades and the post-GRASP grades in freshmen courses. In sophomore level courses the average increase in grades was 6.7 percent. For junior and senior level courses, the analysis did not yield a significant increase or decrease between pre- and post-GRASP course grades.

In terms of retention, McShannon et al. assessed whether students remained in the major one year after the faculty member attended the GRASP program. According to the research team, 997 students were registered during 1999-2003 for GRASP courses and 1,032 were registered in non-GRASP courses. The authors reported an average increase in student retention for students who enrolled in GRASP courses of 7.8 percent for freshmen and 12.9 percent for sophomores, with no significant difference in retention rates for junior and seniors. The authors maintain that the GRASP faculty development program is positively associated with both student achievement and student retention.

Not only are innovative classroom strategies and participation in faculty development programs related to student performance and retention, but faculty attitudes are as well. In a study of environmental effects, Vogt (2008) assessed the impact of academic integration or faculty distance on student self-efficacy, academic confidence, self-regulated learning behaviors, and GPA. Vogt studied engineering students from four universities who belonged to either the Institute of Electronic and Electrical Engineers (IEEE) or the Society of Women Engineers (SWE). In total, 713 students participated in the survey (409 men and 304 women). The study revealed that environmental factors play a statistically significant role in student self-assessments, learning behaviors, and academic performance. For example, Vogt reported that students who felt their instructors showed interest in students, were effective teachers, shared with students, provided opportunities to students, advised them, supported them, and were approachable and accessible (academic integration) scored higher on self-efficacy. Vogt also reported that faculty distance had a negative impact on both students' self-confidence and their self-efficacy. The researcher underscores the role of faculty members in student confidence and self-efficacy, highlighting the need for professors to be available to students as a means of supporting their academic confidence and personal belief in their abilities to succeed.

Overall, this study provides support for the notion that faculty accessibility and support of students is critically important to student confidence in their academic abilities. The environment, as fostered by faculty members, is an important factor in mentoring and nurturing students to be successful in their academic endeavors.

Relevance of Gender-Neutral Research for Women's Education

Despite the absence of analysis by gender, these studies hold important implications for women students. Some inferences can be made about the impact of these interventions for women, given the existing pedagogical literature on women in engineering and learning. Specifically, existing literature points to an increase in women's satisfaction with and persistence in engineering when active teaching approaches are utilized. Each of the projects reviewed in this section employed a novel, active teaching/learning approach to engineering education geared toward student involvement to gain deep learning. Though gender was not directly addressed, it stands to reason that the findings regarding increased learning, program satisfaction, self-confidence, self-efficacy, and persistence in the major based on active learning pedagogical approaches, support programs, and instructor attitude may be generalized to women in particular, as they mirror existing literature on women's learning and persistence in engineering.

Effects of External Resources and Support on Retention of Women in Engineering

A number of diverse approaches to providing external support are used to improve the retention rates of female STEM undergraduates. For example, some involve combining living with learning, requiring students who take classes together to live in the same on-campus residence halls. Others encourage summer research programs aimed at not only completing independent research but also pursuing advanced degrees or careers in STEM fields. Some programs focus on peer mentoring to improve retention or promote membership in professional organizations to provide out-of-classroom supports for female undergraduates. Recent articles on external support programs designed to improve women's retention in STEM fields are reviewed in the following section.

Kahveci, Southerland and Gilmer (2006) examined the impact of The Program for Women in Science, Engineering, and Mathematics (PWISEM), which sought to improve female retention rates through a living-learning community. Students were required to reside together, were provided with study partners, and participated in a one-credit "Women in Science" colloquium. Participants were allowed to reside elsewhere after the first year. The program was based on the assumption, grounded in the literature, that when women students participate in a variety of activities aimed at fostering both student-student and faculty-student interactions, they are more likely to remain in the STEM field.

Kahveci et al. compared female undergraduates in the PWISEM program with female and male undergraduates in Honors General Chemistry who were not in the PSWISEM program over the course of an academic year to see if there were any differences between the groups in terms of interest, confidence, and determination to pursue a science, mathematics, or engineering degree. Thirty-five PWISEM participants as well as 63 Honors General Chemistry students (34 men and 29 women) participated in the survey that was administered as a pre- and post-test at the beginning and end of the semester.

The authors report that women who participated in the support programs for women in the science, mathematics, and engineering fields had higher retention and success rates than both women and men who did not participate in support programs and that the positive outcomes experienced by the treatment group were the result of the PWISEM program. They report that the close student-faculty relationships fostered as a part of the program, the opportunities for research, mentoring, and overall academic networking are associated with retention. The authors suggest that efforts to retain women in engineering should take a holistic approach from the first year of college, through programs such as the PWISEM living-learning community program, which combines a supporting living environment and academics.

Grimberg, Langen Compeau and Powers (2008) evaluated the Clarkson University Research Experience for Undergraduates (REU) Summer Site Program in Environmental Science and Engineering to assess its impact on participants' likelihood of pursuing advanced degrees and careers in science or engineering. The 10-week summer program involved conducting and presenting individual research projects, attending thematic lectures and seminars, participating in community-building activities and field trips, and workshops on further opportunities for research, graduate school, and careers. This article analyzes the pre- and post-participation surveys given to students in the program over the course of seven years. During the fourth year of the program, a weekly seminar on environmental sustainability was added to the program as a way of improving the students' awareness and appreciation of the relevance, impact, and importance of their research and the work of other practitioners on the greater world.

This evaluation of the REU program at Clarkson involved administering pre- and post-test surveys to 78 program participants (41 women and 37 men). The survey assessed students' intent to attend graduate school and their desire to pursue a research career, among other factors. The survey results were mixed. According to the authors, over 60 percent of former program participants had gone on to graduate and professional school programs, but the intention of these students to pursue careers in research fields had decreased after completing the program. While the program does not target women in particular, the results of the research may speak to the intentions of women, since more than half of the participants were female. Overall, Grimberg et al. suggest that participants in the program are likely to continue with their education beyond their undergraduate careers, but not necessarily in STEM areas of study. They conclude that the program is successful in encouraging its students, including its female students, to pursue graduate degrees in general, not just in engineering.

Micari and Drane (2007) evaluated the effectiveness of the Gateway Science Workshop (GSW) at Northwestern University, which is a peer-led, small-group workshop geared toward increasing learning for minority and women in STEM. The authors evaluated five years of data from students in five different STEM subject areas (biology, physics, chemistry, mathematics, and engineering).

The GSW groups are made up of five to seven students (in roughly 100 groups), led by a peer who has taken the course previously, who meet once a week each semester to work through conceptual problems created by the professors of each course. The evaluation of the GSW program involved interviewing 45 students individually (26 women and 19 men), as well as conducting 34 focus groups of 6 to10 students each across science and mathematics disciplines between 2001 and 2005. The results of the interviews and focus groups indicated positive effects for students who participated in the GSW program in terms of higher grades, better retention of students in course sequences, and higher overall course satisfaction compared with non-program participants. These effects, however, appeared more prominent for minority and female students in the GSW program, who experienced even higher grades and higher retention rates in the course sequences than non-minority program participants. According to the authors, this suggests that this peer-led, small-group workshop was able to successfully combat the particular barriers traditionally faced by minority and female students in science and mathematics disciplines in a way that improved their overall college experience. They argue that the informal mentoring and academic guidance offered by peer facilitators is particularly beneficial to women, and that after participating in this program, they feel less isolated and more integrated in their fields of study and universities.

Hartman and Hartman (2005) assessed the impact of professional organization membership on women undergraduate engineering students. The authors compared women university students who participated in discipline-specific, mixed-gender organizations, those who belonged to the student chapter of the Society of Women Engineers (SWE), and those who did not affiliate with student organizations to understand how participation related to professionalism and the development of engineering social capital.

Sixty-two women engineering students participated in the survey that was administered once a semester for one academic year. The researchers report virtually no difference between women undergraduate engineering students who participated in SWE versus a mixed-gender organization in terms of academic achievement, self-confidence, and future commitment to the engineering field. The study did indicate that involvement in professional organizations, regardless of the gender affiliation of that organization, has a positive impact on academic achievement, self-confidence, and future commitment to engineering for women.

Hartman and Hartman argue that their research dispels the myth that female-only professional engineering organizations isolate women further from the engineering field. In fact, they suggest that an overall way to increase female retention in engineering at the undergraduate level is to encourage women to participate in a professional organization, regardless of whether it is intended for women only or both genders, as both have positive impacts on increasing self-confidence and retaining female engineering students.

Overall, the articles in this section indicate that many types of external support are effective in encouraging women to achieve and remain in engineering. The articles reviewed here suggest that participating in networking, mentoring, and community-building activities is associated with higher grades, better retention rates, and higher satisfaction. However, the specific details of support programs may be critical in encouraging STEM commitment as opposed to more generally increasing educational retention, as shown by the Grimberg et al. study.

Longitudinal Analyses of Factors Related to Retaining Women in Engineering Education

In the past few years, several studies have been published examining large datasets in order to better understand the variables that contribute to differences in the training and retention of engineering students and of women particularly. Three studies in particular have contributed unique and valuable information about the factors that help or hinder women's chances of succeeding in engineering programs.

Hartman and Hartman (2006) conducted a study to assess the effectiveness of the Rowan University engineering program. The RU program, established in 1996, was designed to thoroughly incorporate teamwork and interdisciplinary cooperation into the curriculum, while emphasizing a low student-to-faculty ratio and a strong faculty-student mentoring and advising program. The goal was to change the experience of engineering education to make students, particularly women students (who made up only 71 of the 352 students in the study), more likely to succeed and persist in the program.

The study was conducted to assess how successful the program had been in retaining female students and reducing attrition rates generally. The study is ongoing, with surveys distributed twice a year in required classes, reaching almost all students in the engineering program. Hartman and Hartman report longitudinal data collected between 1996, the initiation of the Rowan program, and 2002. Importantly, data were collected from students who left the engineering program before obtaining a degree, allowing for comparisons of "stayers" (n = 319) and "leavers" (n = 33).

Initial analyses of the data revealed not only that Rowan's overall retention rate higher than the national average, but that no significant difference is observed between the retention rate for women (85 percent) and that for men (80 percent). The authors consider these statistics a signal of the success of the program, but go on to examine the factors contributing to the attrition that did occur in the program. Students who left the engineering program had lower grades in high school math and science classes, but also had higher SAT verbal scores, suggesting that attrition may be partially due to a "pulling" effect from other majors or career paths. In addition, leavers did not, on average, have less confidence in their engineering abilities, but rather less confidence in how well suited they personally were for a career in engineering, indicating again that the choice to leave may often be more about the fit of a career in engineering than about an inability to cope with the rigors of the training program.

A large set of analyses by gender revealed several key differences in the attrition patterns of men and women students. Broadly summarized, men students who left the engineering program were generally less well-prepared for the program and had lower grades in their college classes than did stayers. The academic performance of female leavers, however, did not differ from students who remained in the program. Female leavers were more likely than stayers to report concerns about career/family conflicts, as well as reservations about the level of freedom or independence they could expect in an engineering career. The attrition rate was lower among women who participated in the Society of Women Engineers (SWE) on campus or who had engineering internships or jobs while in school, and those with exposure to these experiences also expressed less concern about career-family conflict in the field. The authors suggest that explicitly addressing work/life balance issues with women students can contribute to reducing attrition among female students.

Zhao, Carini and Kuh (2005) used data from the 2001 and 2002 administrations of the National Survey of Student Engagement (NSSE) to assess the satisfaction and involvement of students in science, mathematics, engineering, and technology (SMET) majors. The sample size was 106,460, allowing for comparison of responses by gender and by major, both within SMET majors and between SMET and non-SMET majors.

The NSSE contains questions regarding students' level of engagement on campus (a category broken down into numerous subcategories of engagement experience), self-reported gains of several kinds, perceived level of support in the campus environment, and overall student satisfaction. All student responses were subjective, and no objective information (e.g., GPA or graduation rates) was analyzed in this study.

Though the subjective nature of the data makes it difficult to draw conclusions about the importance of the variables studied in influencing outcomes, the authors note that "female SMET majors are at least as engaged in effective educational practices as their male counterparts" (p. 54). However, the authors note that women do report lower engagement on some measures. Compared to men, women were less likely to ask questions in class or contribute in class and were less engaged with class presentations, teamwork with other students, or tutoring other students. The authors note that reduced female engagement may support an atmosphere of "social tokenism," whereby women in engineering and other SMET fields may perform well academically but are often excluded from a male-dominated network of gossip and strategies for advancement that advantage men in less well-defined ways. Hartman and Hartman suggest a number of ameliorative strategies for improving situations for women and other underrepresented minorities in STEM majors. They suggest that classrooms and curricula be revised to include a wider array of pedagogical techniques and collaborative learning ventures to accommodate students with a wide array of learning styles. They also promote the idea of providing programs and academic counseling services to help women overcome societal obstacles to success in these fields.

Bernold, Spurlin and Anson (2007) surveyed North Carolina State University engineering students over a three-year period, beginning with 1,022 first-year engineering students, of whom 176 were female and 846 were male. The study focused on how student learning styles influence success in engineering programs. The researchers utilized the Learning Type Measure (LTM)[3] to categorize students as one (or more) of four learning types: Type 1 (Why?) students favor discussing ideas, opinions, and subjective information; Type 2 (What?) students prefer to critique information and assimilate abstract facts into coherent theories; Type 3 (How?) students like to experiment and excel at tasks that require objective thinking and measurement; and Type 4 (What-If?) students prefer to use trial-and-error problem solving skills. Students who scored equally high on more than one of the types and students who did not take the LTM were dropped from analyses of the LTM data.

Understanding the role of LTM in outcomes for men and women engineering students is complex. Generally speaking, Type 2 (What?) students had the highest GPA in engineering classes; most of the men engineering students who were categorized were categorized as Type 2 (38 percent, with 75 percent of students categorized). More than twice as many women as men (21 percent and 8 percent, respectively) were categorized as Type 1 (Why?) students; Type 1 students had the second-lowest engineering GPA, after Type 4 (What-If?) students. While these patterns might indicate that women would generally be at a disadvantage, this is not the case. Across all learning types, women students have higher GPAs (average = 3.24) than men (average = 2.97). However, there is no gender difference in the likelihood that freshmen engineering students matriculated into specific engineering majors (a process requiring a minimum GPA in certain classes), a necessary step before students can graduate with an engineering degree. The lack of a difference in matriculating to an engineering major despite women's higher GPAs may be explained by the fact that women were more likely than men to remain enrolled in a non-engineering major, indicating that though they are more objectively successful, many women choose to leave engineering programs anyway.

The data in this study suggest that, on the whole, the women who enter engineering programs do as well or better than the male students; however, possibly due to learning styles that may be less well-suited to a "chalk-and-talk" style of engineering classroom, they are more likely to switch to a non-engineering major. The authors suggest that a broadening of curriculum and classroom teaching styles and strategies would help retain a greater proportion of

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[3] The Learning Type Measure is similar to how Kolb's (1984) Learning Cycle (Why? = Reflecting, What? = Experiencing, How? = Theorizing, and What-If? = Experimenting) has been characterized.

students in engineering, especially those students with learning styles putting them at a disadvantage in a typical engineering classroom.

On the whole, these studies suggest that while women engineering students perform as well or better than men students on objective measures of performance, they are still less likely to complete their engineering programs. Interventions designed to improve the participation and retention of women in engineering must address these challenges in order to be effective.

Summary and Recommendations

Understanding how and under what circumstances women flourish in engineering education is of critical importance to developing and implementing programs that draw women into engineering education and eventually into the engineering workforce. Research presented in this Review shows the promise of carefully designed programs to promote women in engineering education as well as the difficulty of accurately targeting the right combination of supports. Overall, research indicates that many factors and types of programs can help to improve the position of women in engineering. For instance, in-class pedagogical innovations where instructors use student-centered teaching/learning approaches tend to be associated with a better learning experience for students, especially women students (see: Catalano and Catalano 1999; Felder 2005; Nair and Majitech 1995; Riley 2003; Rosser 1999, 1989; Smith, Sheppard, Johnson, and Johnson 2005). Faculty attitudes toward students, including their perceived distance from students, are also related to women's satisfaction and performance.

In addition to in-class teaching innovations and faculty attitudes, women students' success is also affected by the support they receive from broader programs and professional organizations. Longitudinal studies show that some programs and innovations designed to support and nurture women in engineering can be successful over time in providing many women with sufficient support and skills to remain in a STEM field of study.

The articles summarized in this Literature Review provide evidence to support the ongoing development and implementation of additional in-class and programmatic innovations to encourage women's success in engineering. Efforts to bring effective teaching methods to scale could significantly improve the representation of women in engineering.

Further research is needed to identify the specific elements of engineering education that can create barriers to women's success. While this study reports on a number of evaluations, the small number of articles published over the three-year review period that focus on women-centric engineering pedagogies indicates that insufficient resources and attention are being devoted to these promising approaches. We need more information about the ways that teaching methods, faculty/student relationships, curricula, textbooks, other course materials, and the overall academic environment differentially affect women.

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Institute for Women's Policy Research
1707 L Street NW, Suite 750
Washington, DC 20036
(202) 785 5100
www.iwpr.org