A Longitudinal Study of Undergraduate Women in Engineering and Science

Suzanne G. Brainard, Ph.D.[1] and Linda Carlin[2]

[1]Director, Women in Engineering
Affiliate Assoc. Professor, Technical Comm.
Affiliate Assistant Professor, Women Studies
Seattle, WA 98195-2135

[2]Research Assistant
University of Washington
Box 352135
Seattle, WA 98195-2135

Abstract *- With a six-year grant from the Alfred P. Sloan Foundation, the Women in Engineering (WIE) Initiative at the University of Washington is conducting a longitudinal study of undergraduate women pursuing degrees in science or engineering. Now in its sixth year, five of six cohorts of approximately 100 students each year have been added to the study. The objectives of this study are to: (a) determine a more accurate measure of retention by tracking individual students through their science and engineering academic career; (b) examine the factors affecting retention of females in science and engineering; (c) increase the retention rates of female students pursuing degrees in science and engineering by providing interventions for the students themselves, primarily during the freshman and sophomore years which are critical attrition points; and (d) report these factors to the dean and departments involved for consideration in policy development.*

Introduction

Although the national enrollment of women in university engineering programs rose from the 1970's and 1980's to a peak of 19.5% in 1994, women continue to earn only 15.8% of bachelor's degrees in engineering [1]. Despite increased enrollment of female engineering students since the 1970's, retention rates for women have decreased significantly. In the 1972-76 classes, the retention rate peaked at about 90%. However, by the 1983-87 classes [2] the national retention rate for women had dropped to less than 60%, where it has remained to date [3]. Retention rates of female engineering students at the University of Washington in 1991, as reported by the registrar's office, were about 55%. These retention rates are calculated as the fraction of incoming freshman students who complete the engineering program.

Over the past several years, there has been a growing concern for the retention of women and other under-represented groups in the fields of science and engineering (S&E). A primary force driving this concern is due to the influx of these groups into the job market. A lack of technical education and experience in this growing proportion of the workforce will be detrimental to our increasingly technology-oriented society [4].

Another reason for concern for participation of women (and other under-represented groups) in S&E fields is one of financial equity. Our culture rewards those who are competent in technical fields [5]. Although women make up 46% of the total labor force, they comprise only 31% of the science professions (excluding social science) and only 9% of the engineering profession [6]. Without access to decision-making positions in technology, women and other under-represented groups will continue to be denied economic and social power.

Until the early 1990's, the focus of research on the issue of successfully recruiting and retaining women in technical fields focused on the students themselves. Was their high-school preparation inadequate? Were they unable to compete in math? The response of faculty and administrative personnel in many S&E undergraduate programs to students who switch or drop out has traditionally been that the students were just in the wrong field, and it was better for all concerned to weed these people out of the S&E programs [7].

However, in their benchmark 1994 study comparing students persisting in S&E undergraduate degree programs with those who chose to switch to another field of study, or drop out of college altogether, Seymour and Hewitt found that there were no real differences in high-school preparation, ability, or effort expended in their coursework between students who remain and those who switch. Although these results were for both male and female undergraduates, they have been confirmed by other studies of female S&E undergraduates [8 & 9].

Further, among those who switch, there are two categories who may have made significant contributions had they been retained: "those who are pulled more than pushed, and those who are pushed more than pulled" [10]. Students in the first group are high-achievers who are disappointed or bored with the S&E curriculum and look elsewhere for their education. These students often express an ambivalence about their decision to switch. The second group is comprised of students who chose to pursue a science or engineering degree because of personal interest, yet feel forced to leave due to a loss in confidence and difficulty with poor teaching and the competitive environment. These students often express anger at feeling forced to find an alternative to their first choice of career. Seymour and Hewitt's findings placed many women and students of color in this second category.

These findings are supported by an earlier study of young women in high-school [11] who tended to suffer from

a loss of perceived academic competence. While only males of low competence dropped out of math and science courses, females of high competence were often also dropping out. These young women had experienced a loss of self-confidence prior to any exhibited loss of performance in their math and science classes. Therefore, it was not lack of academic ability that diverted these young women from continuing math and science.

Partially as a result of Seymour and Hewitt's findings, research in this area has begun to shift toward a focus on the educational climate of these S&E programs [12]. Why are so many competent students choosing to leave? What policy changes can be made to improve the quality of S&E education and encourage retention of a broader pool of students?

Ginorio, who proposes an integrated model of science education, argues that the main issue of changing the climate in S&E programs is to realize that equality does not mean "sameness." Again, we see a shift in thinking from instructing all students to follow the traditional model of success, to recognizing that students bring different experiences with them to their education and are capable of making different contributions. The successful establishment of women in engineering programs at several universities [13] is an acknowledgment of the theory that, given support and opportunity, women can not only survive, but thrive in a traditionally male-dominated field. However, of the more than 200 institutions in the United States that now list some activity supporting women in engineering, only 66 currently have full programs with directors appointed for 50% time or more. Of those 66 programs, only eight formally evaluate the effectiveness of their programs, and only three collect longitudinal retention data that reflects individual rather than aggregate data.

The inadequacy and inconsistency of collection and maintenance of evaluation and retention data is a national problem, and one that was identified in 1988 by the National Research Council (NRC) as a major hindrance to projecting future manpower needs as well as identifying problem areas in the pipeline. The NRC established a formal committee to investigate ways to improve this process not only at the federal agency levels, but also at the institutional levels. Although mandates for federal agencies can be put in place, it is more difficult to do for educational institutions. Collecting and maintaining longitudinal tracking systems on all registered students is a complicated and expensive endeavor. As a result, only a handful of institutions have implemented such processes. At this point, most institutions do not have an incentive to bear the burden of the costs of instituting such tracking mechanisms. Most retention rates, as Bowen [14] points out, are inflated, because the method of calculation, which uses aggregate data rather than individual tracking, does not account for student transfers into engineering after the freshman year.

One of the goals of WIE's longitudinal study of female engineering and science students is to obtain a more accurate measure of retention of females pursuing science and engineering degrees by tracking individual students until they graduate [15]. At present, only a handful of institutions track individuals over the course of their academic career. Unfortunately, there are currently no parallel data available to compare males in science or engineering, or females pursuing other degrees to act as comparison groups for this study.

At the University of Washington, about 4000 freshmen (50% are female) are enrolled annually. During their freshman year, all S&E students are enrolled in the College of Arts and Sciences. At the end of the freshman year, students have the option to register as pre-science, and qualifying sophomores are designated as pre-engineering. After completing the pre-engineering requirements, students are eligible to apply for one of ten engineering departments. As a result, students do not enter the College of Engineering or departments of science until their junior year. It is only at this point in the beginning of the junior year that students are tracked individually by the college/department.

Given the lack of more precise national and institutional retention data, and the desire to have a better picture of how well female S&E students are faring, the goals of WIE's retention program are to: (a) determine a more accurate measure of retention by tracking individual students through their science and engineering academic career; (b) examine the factors affecting retention of females in science and engineering; (c) increase the retention rates of female students pursuing degrees in science and engineering by providing support resources for the students themselves, primarily during the freshman and sophomore years which are critical attrition points; and (d) report these factors to the dean and departments involved for consideration in policy development [16 & 17]. The results of the first five years suggest that the program has had a significant impact on increasing retention rates of female freshmen pursuing degrees in both science and engineering.

Method

Instrument Design and Data Gathering

Six instruments have been designed to gather information: the Annual Freshman Interest Survey, Freshman Initial Interview Form, Freshman Follow-up Interview Form, Sophomore Follow-up Questionnaire, Junior Follow-up Questionnaire, and Senior Follow-up Questionnaire.

The Annual Freshman Interest Survey is mailed in August of each year to all incoming female freshmen to determine how many are interested in pursuing degrees in science or engineering. About 2000 surveys are mailed each year, of which approximately 300-350 responses are returned.

Of those responding to the survey, approximately 100 students interested in engineering and 25 students interested in science are selected to participate in the study. Using a

structured interview form, an initial, personal interview is conducted with each student at the WIE Study Center during the Autumn Quarter. A second, follow-up interview is conducted either in person or over the telephone during Spring Quarter. Sophomores, juniors, and seniors are sent (via electronic or regular mail) a follow-up questionnaire. All students not responding to the questionnaire are contacted to complete the questionnaire over the telephone.

Reviewed and approved by the University of Washington Human Rights Committee, the structured interview forms are used to ensure that the students' rights of confidentiality and safety are honored and the same information is gathered on each student. The following information is gathered: demographic information; education and professional background; academic interests; amount of family, peer and financial support; confidence level; and perceptions of campus climate and quality of teaching. Students participating in the study must sign a release form consenting to participate.

Tracking System

The WIE tracking system provides a mechanism for measuring retention rates, monitoring student participation in activities, and analyzing data each year. Utilizing the SPSS statistical package, data from the tracking system is analyzed to: (a) identify individual problems potentially leading to changing majors or dropping out of science and engineering; (b) analyze trends and patterns of barriers that tend to influence the retention of entering female freshmen; and (c) provide a mechanism for accountability in measuring the effectiveness of the WIE's efforts to increase the retention rates of female freshmen.

Interventions

A series of interventions (or contact points) are implemented by personal contact with each student throughout her academic career at the University of Washington, focusing primarily on the freshman and sophomore years, when students are not yet accepted into their respective departments, and are at the greatest risk of switching out of science and engineering. These contact points involve academic and social support. Students are interviewed to discuss their academic goals, make plans for the future, and participate in activities with a community of peers. The contact points include personal interviews, an orientation session, peer tutoring, peer mentoring, and quarterly seminars and events. WIE also facilitates an engineering mentoring program which matches students with professionals working in their field of interest. This program, now in its sixth year, has had great success in providing students with "real-world" experience, as well as improving their self-efficacy in their academic challenges [18].

Analyses and Results

Freshman Interest Survey

To date, the annual Freshman Interest Survey has been mailed to five consecutive cohorts of all incoming first-year female students at the beginning of Autumn Quarter [19]. Cohort 1 began its first year in 1991 and has graduated or completed its fifth year; Cohort 2 began its first year in 1992; Cohort 3 began its first year in 1993; Cohort 4 began its first year in 1994; and Cohort 5 began its first year in 1995 and are now sophomores. The response rates of students to the annual Freshman Interest Survey and the numbers participating in the initial first-year interview are summarized in Table 1 below.

Table 1: Response Rates to the Freshman Interest Survey

Freshman Interest Survey	**Cohort 1**	**Cohort 2**	**Cohort 3**	**Cohort 4**	**Cohort 5**
Surveys mailed	2100	2525	1900	2100	2118
Surveys returned	150	358	200	512	474
Students interested in S&E	110	332	183	483	394
Students interviewed	92	107	103	125	127

Persistence in Engineering

The student responses to the interviews show that there are a number of common factors influencing a student's decision to persist in engineering or science, to switch to another major, or to drop out of school altogether. Tables 2-5 summarize the factors which have shown, based on chi-square analyses, a significant correlation ($p < 0.1$) with persistence in engineering or science. These factors are then ranked according to their relative importance as a predictive factor of persistence, based on a stepwise logistic regression analysis model using persistence as the dependent variable. Persistence of 5th-year students was 100%.

*Table 2: Persistence Factors in S&E at the End of the First Year, Cohorts 1-5 **

Variables	χ^2	χ^2 p value	Logistic Regression p-value
Enjoy science classes	21.02	.004	.002
Career opportunities	7.17	.028	.011
Enjoy math classes	20.74	.002	.021
Positive influence of WIE	5.00	.083	.137
Positive influence of Faculty/TAs	5.23	.073	.794
Interest in coursework	6.99	.030	.850
No problem working independently	14.49	.043	.947

** N=355; due to refinements to the questionnaire, not all students responded to all questions*

In the first two years of preparation for entering an engineering department, students at the University of Washington are required to take technical core courses, which include a series in math, physics and chemistry. The primary factors which seem to help these women decide to continue in engineering or science beyond their first year in college are interest in their math and science courses, a positive influence of WIE and faculty, and being able to work independently. For the first time this year, career opportunities emerged as a factor in persistence.

By the end of the sophomore year, the primary factors related to persistence continue to be the student's experience in math and science classes (see Table 3). In addition, committing to an engineering or science degree by registering as a pre-engineering or pre-science student (as indicated by their registration status) and gaining acceptance into a department become major factors in persistence. The positive influence of an advisor and working during the school year emerged as persistence factors this year for those completing their sophomore year.

*Table 3: Persistence Factors in S&E at the Sophomore Year, Cohorts 1-4**

Variables	χ^2	χ^2 p value	Logistic Regression p-value
Positive influence of advisor	8.79	.012	.032
Acceptance into the department	8.72	.013	.059
Influence of math & science classes	29.24	.000	.286
Working during the school year	5.08	.024	.347
Registration status	40.48	.000	.391

** N=284; due to refinements to the questionnaire, not all students responded to all questions*

By the junior year, a student is accepted into a department, reflected by registration status as a predictor of persistence (Table 4). Other persistence factors include influence of a mentor, the positive influence of math and science courses, and working during the school year. A new persistence factor emerging this year is the experience in student societies and at conferences and events.

*Table 4: Persistence Factors in S&E at the Junior Year, Cohorts 1-3 **

Variables	χ^2	χ^2 p value	Logistic Regression p-value
Registration status	5.71	.127	.107
Influence of math & science classes	8.27	.016	.442
Positive influence of a mentor	7.24	.027	.569
Conferences, events, student societies	7.03	.030	.587

** N=222; due to refinements to the questionnaire, not all students responded to all questions*

Involvement in the WIE Big Sister Program emerged as a primary predictor of persistence for seniors this year (Table 5). As in previous years, the influence of an advisor or mentor, WIE, and experiences in math and science courses continue to be related to persistence. Again, not all of the women reporting a positive influence of WIE on their academic experience had actually participated in WIE programs, reflecting the support that the mere presence of a program like WIE can have for some students. New factors emerging this year include positive experiences at conferences and events, and plans to work in an engineering job after graduation.

*Table 5: Persistence Factors in S&E at the Senior Year, Cohorts 1-2 **

Variables	χ^2	χ^2 p value	Logistic Regression p-value
Involvement in WIE Big Sister Program	.079	3.09	.154
Positive influence of WIE	6.47	.039	.541
Positive influence of science courses	8.82	.012	.628
Positive influence of a mentor	5.78	.016	.891
Conferences & events	8.38	.004	.905
Plans to work in an engineering job	3.35	.067	.909
Positive influence of advisor	6.69	.035	.960

** N=135; due to refinements to the questionnaire, not all students responded to all questions*

Perceived Barriers to Persistence

For those women who do choose to remain in engineering and science, there are a number of barriers to persistence frequently perceived at each stage of their education. The most frequently reported barriers are summarized by years in school in Table 6. Because of ongoing refinements to the annual interviews and questionnaires, not all questions were asked of all cohorts. Therefore, as shown in the column headings, the response rates below represent only those students who responded to these questions, rather than the entire study population.

As in previous years, two of the most frequently perceived barriers for first-year students and sophomores are lack of self-confidence and concern about not being accepted into their department when they apply at the end of their sophomore year. Feeling isolated also emerged this year as common concern for all but first-year students.

Approximately 25-30% of the first-year students, sophomores and juniors report that they feel no barriers to persisting in their engineering or science education. Surprisingly, by the time they are 4th- and 5th-year seniors, almost all of the remaining women in our study, many of whom had earlier reported perceiving no barriers to their academic progress, report at least some barriers. In addition to the barriers reported in Table 6, these 4th- and 5th-year seniors report feeling discouraged by low grades (42.2%), and complain about poor teaching (50.1%) and unapproachable faculty (40%). The percentage who report low self-confidence as a barrier has more than doubled the percentage reported by first-year students. Further, concerns about lack of interest, poor advising, financial problems, and feeling intimidated increase dramatically by the senior year.

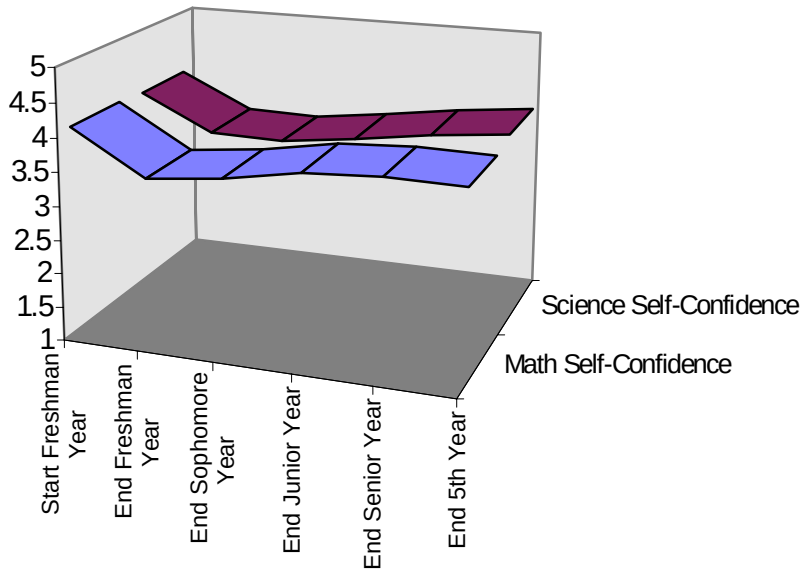
Table 6. Most Frequently Reported Perceived Barriers

	First Year (n=488)	Sophomores (n=218)	Juniors (n=88)	Seniors (n=100)	5th Year (n=16)	Average
Lack of self-confidence	23.5%	26.6%	23.9%	45.0%	69.0%	37.6%
Feeling isolated	8.1%	32.6%	40.9%	47.0%	50.0%	35.7%
Lack of interest	12.6%	21.6%	18.2%	41.0%	62.5%	31.2%
Financial problems	15.0%	22.9%	20.5%	32.0%	25.0%	23.1%
Not being accepted into department	27.4%	32.0%	9.1%	N/A	N/A	22.8%
Feeling intimidated	17.0%	15.6%	8.0%	21.0%	31.3%	18.6%
Poor advising	7.0%	12.4%	13.6%	37.0%	12.5%	16.5%
None	27.6%	32.6%	25.0%	2.0%	0	21.0%

Level of Confidence

Levels of self-confidence in academic achievement in S&E were measured on the basis of responses to questions asking the students to rate themselves as math and science students compared with their peers on a 1-5 Likert-type scale. As in previous years, most of the women students entering engineering and science begin with a very high level of self-confidence in their abilities in math and science (mean scores: math=4.1; science=4.0). However, both of these levels of self-confidence drop significantly ($p < .01$) over the course of their first year (mean scores: math=3.4; science=3.5). Figure 1 illustrates this significant drop.

Figure 1. Mean levels of self-confidence by year.



Students who do maintain a high level of self-confidence in the first year report enjoyment of math and science classes, considering competition to be a motivator, having friends who are interested in S&E, and a positive influence from male friends, WIE, and other student societies, conferences, and events.

Overall self-confidence levels begin to increase slightly from the general first year decrease by the end of the

sophomore year. Primary predictors of high self-confidence at this point are positive ratings of teaching quality, interest in coursework, participating in a study group, and a positive influence of technical courses, faculty and mothers.

The continued increase in confidence at the end of the junior year reflects having been accepted into a department. In addition, self confidence is predicted by a positive influence from male friends, an advisor, and mothers.

High levels of self-confidence for 4th- and 5th-year seniors correspond to participation in student professional societies, interest in coursework, working during the academic year, career opportunities, and a positive influence of science courses, male and female friends, and an advisor. It should be noted, however, that the overall levels of self-confidence never return to the original high level of entering first-year students.

Retention

One of the primary goals of this study is to calculate accurate retention rates of women in S&E. The retention rate at the University of Washington prior to this study was about 55% as cited by the University Registrar. However, the University of Washington's retention rate and the national retention rate of 60% are considered inaccurate, because this rate is calculated simply on the basis of entering vs. graduating students. This number results in an over-inflated retention rate because it does not account for inflow of students after the first year [10]. The retention rates reported in Table 7 are the first accurate calculations based on tracking individual women throughout their college career. With no intervention in place, it would be expected that these rates would fall below the over-inflated rate of 55%. The results of this study indicate that the retention rates of women in engineering and science at the University of Washington have increased substantially since the inception of the WIE Undergraduate Retention Program.

Table 7. Retention of Students in S&E at the UW.

Cohort	Current Status	Original N	Still in S&E	%
1	End 5th year or graduated	92	69	75%
2	End senior year or graduated	107	78	73%
3	End junior year	103	62	60%
4	End sophomore year	125	87	70%
5	End first year	127	114	90%

An analysis of incremental retention rates reveals patterns of switching out of S&E. As shown in Table 8, most women who leave S&E do so during their sophomore year. This switching coincides with the time when most students find out if they have been accepted into a department, as well as the point of lowest academic self-confidence which was shown in Figure 1. For those women who remain in S&E beyond their sophomore year, retention rates are very high.

Table 8. Incremental Retention by Year in School

Cohort	First Year	Sophomore	Junior	Senior	5th Year
1	97%	84%	97%	95%	100%
2	93%	89%	94%	94%	
3	87%	83%	83%		
4	80%	87%			
5	90%				

Switching Out of Engineering and Science

A total of 54 of the 313 students who responded to the interviews and questionnaires from the five cohorts surveyed this year switched out of S&E or dropped out of college altogether. The majority of these students were first-year and sophomores. None of the sixteen 5th-year seniors responding to the questionnaire reported switching. This

drastic increase in the retention rate at the junior and senior years is expected, since these students have persevered through the hurdles of the lower-level prerequisite courses and acceptance in their department at the end of their sophomore year.

The most frequent reasons given for switching are summarized in Table 9. Responses from all cohorts over the five years of the study have been fairly consistent: loss of interest in engineering and science, other majors appear more interesting, and discouragement by conceptual difficulties and low grades. This discouragement corresponds to the drop in self-confidence over the course of the first year. Note that the responses in Table 7 do not reflect the entire 144 students who have switched or dropped out, but only the 120 students who responded to the survey at the point of switching or leaving the University of Washington.

Table 9. Most Frequent Reasons for Not Persisting in S&E

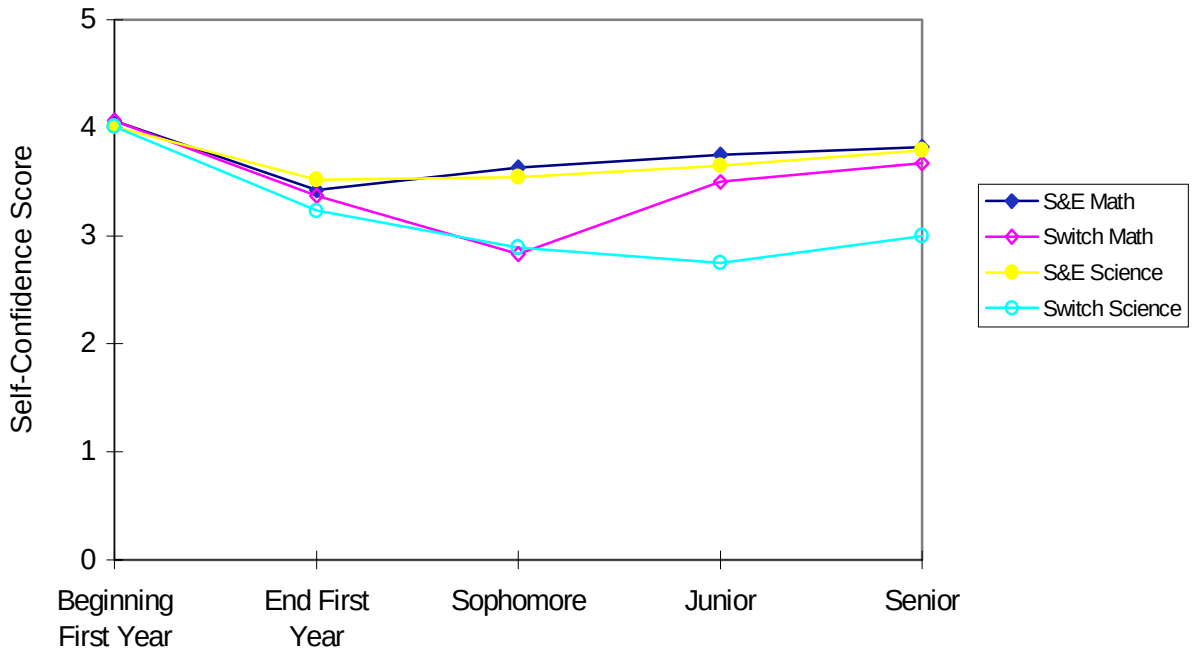
Reasons	**First Year (n=48)**	**Sophomores (n=50)**	**Juniors (n=15)**	**Seniors (n=7)**	**5th Year (n=0)**
Other majors more interesting	40%	40%	47%	57%	N/A
Lost interest in S&E	58%	57%	67%	57%	N/A
Conceptual difficulties	29%	46%	36%	29%	N/A
Discouraged by low grades	50%	60%	47%	57%	N/A
Rewards not worth the effort	29%	20%	21%	29%	N/A
Poor Teaching	32%	28%	86%	43%	N/A

Total N=120

An additional survey this year of women who had switched to other areas of study revealed that there is no significant difference in performance levels (measured by GPA) of women who persist and women who switch out of engineering and science degree programs. The mean GPA for both groups is approximately 3.2 on a 4-point scale. Clearly these women do not leave S&E due to academic problems.

However, there were differences in academic self-confidence in these groups for those who switched during their sophomore or junior years. Further investigation of this finding revealed that both math and science self-confidence levels for switchers are significantly lower than persistors in the sophomore year, continuing downward from the drop in self-confidence reported for all study participants at the end of the first year. Science self-confidence remains significantly lower for those who switch during their junior and senior years. Interestingly, math self-confidence levels for women who switch in later years are equal to those who persist in S&E. As mentioned previously however, the trend for both groups is an overall decline in academic self-confidence from when they first entered college. This consistent finding of no relation between academic self confidence and performance in women replicates findings in other studies [20].

Figure 2. Academic Self Confidence Measures for Women who Remained in S&E vs. Women who Switched to Another Major



Conclusion

In summary, there are several factors forming a general, consistent pattern describing the academic experiences influencing the decisions of women to persist in, or switch out of, degree programs in engineering and science:

- The women who enter the University of Washington with the intent to pursue a degree in engineering or science are highly-filtered achievers who start off with high levels of self-confidence in their academic abilities in math and science. These levels take a significant drop ($p < .01$) over the course of the first year, and although they slowly recover over the course of their four or more years in college (if they persist in S&E), they do not return to their original levels.
- The first and sophomore years are the times when women are most likely to switch out of an engineering or science degree program. The primary reasons given for switching are a combination of losing interest in science/engineering, being attracted by another field, and being discouraged by academic difficulties and low grades.
- Not surprisingly, the reasons for leaving are also the most frequently reported concerns, or "barriers to progress" reported by women students who persist: fear of losing interest, intimidation, lack of self-confidence, poor advising, and not being accepted in their department. Although 25-30% of first-year students, sophomores and juniors reported no barriers, nearly all seniors reported at least one barrier.
- Women who are most likely to persist through the first year chose to pursue their major primarily because they enjoyed their science and math classes in high school, continue to enjoy those classes in college, and work well independently. In addition, they had considered WIE and faculty to have a positive influence on them during their first year in college. Awareness of career opportunities in S&E also emerged this year as a persistence factor.
- In the sophomore year, persistence factors focus primarily on continued enjoyment of math courses, a positive relationship with an advisor, and the reassurance that comes with acceptance in their department.
- In the junior year, after being accepted into a department, persistence factors shift to interest in coursework, influence of a mentor, and experiences in student societies, at conferences and other events.
- Finally, for seniors, persistence continues to be related to the student's sources of support - her advisor, a mentor, and WIE, particularly the Big Sister Program. Persistence is also related to continuing interest in coursework, experiences at conferences and events, and plans to work in an engineering job after graduation.
- There is no difference in GPA between women who persist in S&E and women who switch to a non-science major. However, there is a significant drop in math and science self-confidence reported by those women who switch during their sophomore year. Science self-confidence is also significantly lower for women who switch in the junior or senior year; however, there is no significant difference in math self confidence between switchers and persistors.

These findings suggest that there are factors in the engineering and science curriculum and environment that need to be examined. In response to the criticism that low retention rates may be caused by the fact that students receive little engineering instruction until the junior year, some departments in the College of Engineering have instituted policy changes making it possible for students to begin the engineering curriculum in the sophomore year rather than the junior year. This new policy will more than likely positively influence the retention rates. The impact on retention of this change in the curriculum structure will be examined as an ongoing part of the present study.

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