

Women's Entry to Graduate Study in Computer Science and Computer Engineering in the United States

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Abstract

What factors are related to the gender composition of graduate computer science and computer engineering programs? Data from a nationwide survey of graduate computer science departments in the U.S.A. address this question. Our exploratory analyses indicate that program flexibility, active recruitment, and effort to recruit women are all associated with the gender composition of these departments, but not necessarily in the predicted manner. Women's representation appears to be highest in flexible programs that put effort into recruiting women. But when men in the department meet with prospective students, recruitment of male students is likely to far outpace recruitment of women.

Research Objective and Theoretical Perspective

Our objective is to identify factors related to women's representation in graduate programs in computer science and computer engineering (CSE) in the United States.

Minimal previous research exists on this topic. As a consequence, we look to research from other science, technology, engineering, and mathematics (STEM) disciplines, the workforce, and undergraduate computing to guide our work and suggest hypotheses. From graduate programs in STEM, we know that women's representation varies with the type of student-faculty interactions prevalent in a department (Fox 2001). From the workforce, we know that women's representation in a firm is affected by formal and informal hiring practices (Reskin 2003), social networks (Reskin 2003; McPherson et al. 2001), and employer and employee preferences and stereotypes (Reskin et al. 1999; Gorman 2005). From undergraduate computing, we know that institutional gender composition is related to department gender composition, and that college men and women are drawn to computing under very similar circumstances (Tillberg & Cohoon 2005; Cohoon 2006). It is unclear, however, which, if any, findings transfer from these arenas to graduate CSE.

This paper describes some findings from the first large-scale empirical study of women's representation in graduate CSE programs. For our analysis, we consider how student preferences and departmental recruitment practices influence the gender composition of graduate enrollment. Consideration of other factors is deferred to future analyses. If the effects of preferences and recruitment practices follow patterns observed in other settings, we should see that there are few differences in the program features that men and women find attractive, faculty attitudes and behaviors regarding diversity affect women's representation, and formalized recruitment practices increase women's representation.

Research Methods

We recruited departments for the survey from a stratified random sample of all the U.S. post-secondary institutions with active doctoral programs in computer science or computer engineering. Forty-nine departments participated in the data collection, but the doctoral program in one institution was inactive, so this program was dropped from the analysis. Two outlier departments were also dropped from the current analysis because of apparent problems with the data for their dependent variable. The resulting data set is thus from 46 CSE departments, with 18 considered top-tier and the rest divided equally into middle and bottom tiers in academic

quality. (Tiers are based on 1993 National Research Council rankings, with departments divided into thirds to comprise tiers.)

In the spring of 2003, we collected survey data using three instruments: chairpersons, faculty, and graduate students. All full-time graduate faculty, and in most cases all students, in a department were invited to participate. In especially large departments, we randomly sampled up to 85 students, oversampling women up to 50%. The surveys were implemented through the web. We sent out multiple email reminders, and non-respondents received a paper questionnaire follow-up. The subsequent response rates from the original sample were 94% for chairpersons (46 chairs, 43 in the data used for analysis), 63% for faculty (789 faculty, 749 in the data used for analysis), and 55% for students (2012 students, 1949 students in the data used for analysis). Response rates for particular questions varied.

Survey questions used a five-point scale to measure the attitudes and practices of students and faculty. Students were asked to rate the importance of various factors in their decision to pursue a graduate degree in CS/CE and in the selection of their current program. Another set of student questions measured their level of agreement with various statements about intended career. The student survey also asked if students had ever helped recruit new graduate students. The faculty questionnaire asked how often they engaged in different recruitment activities and how much importance they placed on various criteria when evaluating applicants. To measure the outcomes of faculty recruiting practices, we asked chairpersons how many part- and full-time male and female students were enrolled in their program.

Initial analyses for male-female differences were done on the individual level. For all analyses relating recruitment practices to the female proportion of enrollment, data were aggregated to the department level. Program tier was investigated as a relevant factor in women's representation but was dropped from the analysis when no significant findings were obtained.

Findings

We considered two issues – how are men and women similar and different in what they seek in a graduate CS education and a particular program, and what recruitment and admission practices are employed by graduate CS programs. For both preferences and recruitment and admission practices, we measure correlation with women's representation.

Program choice is based on many similar, although often differently weighted, features.

Descriptive statistics from individual responses identified the leading factors that graduate students thought affected their choice of program and the features that particularly appealed to female students. In this section, we report the most influential factors, along with some factors that students considered less important but that show some potentially interesting gender differences. The full set of program choice factors considered by survey respondents is given in Appendix A.

Men and women choose graduate study in CSE and their particular programs for similar reasons.

On average, the men and women who pursue graduate study in CSE do so for very similar reasons. The factors that respondents rate as most important in their decision to pursue the degree and in their selection of a program are the same for both sexes. Men and women both put “interest in or enjoyment of computing” as their number one reason for graduate study of this discipline. But, although sex was not a factor in the *ranking* of factors that influenced student decisions to pursue a graduate degree in CSE, there were sex differences in *ratings*. Men rated

interest and enjoyment as 4.2 on a scale where 1 is not at all important and 5 is extremely important, and women rated it 4.1. Analysis of variance indicated that this gender difference was statistically significant at the .01 level, and it persists when degree program is taken into consideration. So, regardless whether students are pursuing a master or doctorate degree in CSE, men more than women indicate a stronger influence on their decision to pursue the degree by interest in and enjoyment of computing.

As with decision to study CSE at the graduate level, men and women also chose their particular program for similar reasons. Table 1 shows that their most important consideration was reputation – of the institution and of the program or professor(s). For women, the next most important factor in selecting a graduate program was the availability of financial aid, followed by research opportunities and area of specialization. For men, the next most important factor after reputation was research opportunities, followed by the availability of financial aid. Among these most influential factors, only the gender differences in the importance of financial aid and area of specialization were statistically significant.

Table 1 also shows other potentially consequential gender differences that exist for program choice factors that were rated only moderately important. For example, environment in the department was more important to women's decisions than to those of men. Impressions of faculty and department culture were both moderately important to women but slightly less important to men. Women also placed more importance than men on flexibility in program content and geographic preferences or constraints. All of the gender differences in these factors were statistically significant.

Finally, women cared more than men did about the presence of women among faculty and students, but neither group thought this factor was very important. Women rated the importance of women's presence among students as between slightly and moderately important (2.4), and rated women's presence on the faculty at about the same level of importance (2.3). Men thought these factors were less important still (1.9 and 1.6, respectively).

Flexibility is the only program feature with evidence of a positive relation to women's representation.

Correlations between the items in Table 1 and women's representation (measured as the female percent of enrolled graduate students according to chairperson reports) show only one significant relationship: a moderately strong positive correlation between "flexibility in program content" and women's representation in a program ($r=.35$, significant at the .01 level). This correlation indicates that CSE departments with flexible programs are particularly attractive to women.

Recruitment and admission practices that lead to gender balance are difficult to identify.

In addition to asking students what attracted them to departments, we asked faculty members about their recruitment practices. We aggregated their responses by department to assess how common each practice was in each department. The recruitment practices are listed in Table 2 with measures of their mean reported frequency on a scale where 1 represents "never" and 5 represents "always." Table 2 also lists correlations between recruitment practices and department's effort devoted to enrolling women graduate students (aggregated mean responses to "In your opinion, how much effort does your department devote to enrolling women graduate students?" with response options on a five-point scale from "no effort" to "very extensive effort.") These correlations indicate some positive associations with effort, but none with

women's representation (not shown). Women's representation is positively correlated with department effort to enroll women, however, although the specific practices that lead to gender balance are difficult to identify.

More than a little effort is necessary for increasing women's representation.

Effort departments put into enrolling women graduate students appears to pay off – departments that put more than “a little effort” into women's recruitment tended to enroll higher percentages of women.

Faculty responses to the question about effort showed that the average department put slightly less than a “moderate” amount of effort toward enrolling women. Departments ranged from “a little” effort to effort rated between “moderate” and “extensive.” No departments were rated by their faculty as exerting “extensive” or “very extensive” effort.

Among departments putting more than “a little” effort into enrolling women, greater effort was associated with greater women's representation ($r=.40$, significant at the .01 level; $n=34$). In other words, there appears to be a point at which effort begins to result in measurable increases in women's representation. Below that point, graduate enrollment in departments exerting little or no effort ranged widely from 16 to 31 percent women. There was no measurable relationship between effort and women's representation at the low end of the effort spectrum. At the mid to high end of the effort spectrum, however, more effort was associated with greater gender balance.

What does “effort” mean? Both faculty and chairperson responses suggest that recruiting from liberal arts and women's colleges are efforts to recruit women. Even so, in the average department, recruitment from these types of undergraduate programs is performed between “never” and “rarely.” At most, faculty reported recruiting from women's colleges or liberal arts colleges “rarely” or “sometimes.” Other less strongly correlated components of effort were indicated by faculty and chairpersons, but none had a significant positive relationship with women's representation.

Why would effort be related to women's representation when none of the practices associated with effort are related to women's representation in the expected manner? There are several possible explanations. It may be that “effort” refers to something other than the practices we specified. Alternatively, effective effort might require combinations of practices, and the correct combination might vary by department. Another possible explanation is that effort might be expended only by a designated person or group while the average faculty member operates in ways that reinforce the status quo.

The role of effort requires further investigation to untangle its non-linear relationship with women's representation. For the remainder of this paper, we explore the effects of one type of recruiting practice that had a significant, but unexpected, effect on women's representation.

Although personal recruiting by faculty may be productive, it failed to show the expected positive effect on women's representation.

Most faculty members believe that meeting with prospective students and encouraging them to apply is the most effective means for increasing the number of women in their graduate program. Both male and female faculty members endorse this method, but that does not mean that they employ it, nor does it mean that their goal is to promote gender-balanced enrollments when they do employ it.

Slightly more than half (54%) of the faculty in the average CSE department frequently meet with prospective students. This action appears to be an effective recruiting practice in that it was strongly associated with graduate student reports about the importance of their "impression of faculty during a campus visit." Table 3 shows that male and female CSE students were more likely to consider the impression they got of faculty to be important in their choice of program if faculty members met with prospective students often. This relationship suggests that faculty members do help recruit graduate students, at least graduate students who consider their impression of faculty members to be important, as women are slightly more likely than men to do.

Not shown in Table 3 is that instead of the expected positive association between women's representation and faculty efforts to recruit students through personal meetings, there was a moderately strong *negative* correlation between the average frequency of meeting with visiting prospective students and a department's female percent of graduate enrollment ($r = -.50$, significant at .01). Similarly, if the average faculty member in a department took an active approach to recruiting and called or mailed prospective students, their program was likely to have low female enrollment ($r = -.51$, significant at .01). This finding corroborates results from a nationwide pretest of our survey questions. The pretest showed that meetings between faculty members and prospective graduate students had a statistically significant negative relationship with women's representation in departments that had low National Research Council ratings (Cohoon and Baylor, 2003). Our current study indicates that this relationship is also common to the average CSE graduate program, regardless of its rank.

Table 3 indicates similar, but weaker, relationships between recruiting by female faculty and importance of impression. Perhaps the reason for the weaker correlations is that women faculty comprised only 15 percent of the responding faculty in the average department and so were less available to meet with the similarly scarce women prospective students. This scarcity could also explain why women's enrollment is independent of their impression of women faculty.

Faculty meeting prospective students might negatively affect women's representation for several reasons. It is possible that women comprise a smaller number of applicants in the departments where personal recruiting is often practiced. This situation would look like effective recruiting together with low female representation. An alternative explanation is that meeting prospective students is an effective tool insufficiently applied to recruiting women. Among the faculty members who reported frequently meeting with prospective students, 18 percent indicated that they do not believe their department should actively recruit members of under-represented groups. This minority could be wielding an effective recruiting tool in a manner that advantages men over women.

Although students generally may be effective recruiters, recruitment by current graduate students failed to show the expected positive effect on women's representation.

Close to one-third of graduate students in the average department say they helped out in the recruitment of new graduate students. In the departments where many current students helped recruit new students, graduate students generally reported that their impression of current students was important in the decision to enroll in that program. This relationship included women; there was a moderately strong correlation ($r = .55$, significant at .01 level) between

women's rating of how important their impression of students was and the percent of students in a department who helped recruit new graduate students.

Our analysis, as shown in Table 4, indicates that recruiting by experienced graduate students was moderately correlated with first-years who considered their impression of students during a campus visit to be important in their selection of a graduate program. The relationships suggest that students can help recruit students to their graduate program.

We also see from a comparison of the first and second columns in Table 4 that women recruiters appealed more than men recruiters to both men and women applicants. This observation suggests that because they also attract men, women graduate student recruiters do not improve the gender imbalance despite the positive influence they have on prospective women. These findings may help explain why women students' recruitment efforts had no measurable direct association with women's representation in their departments.

Effective recruiting by men may advantage men.

Without data on the gender composition of program applicants, we cannot examine the ad hoc hypothesis that personal recruiting actually yields more gender balanced enrollments than would otherwise occur. For now, we consider another explanation for how personal recruiting can be both effective and negatively related to women's representation.

CSE departments are typically majority men among both faculty and graduate students. As these male department members meet with prospective students, they are more effective at recruiting men than recruiting women. In departments where male faculty members met often with prospective students, women's representation was lower than in departments where this action was seldom taken ($r = -.43$, significant at the .01 level). Likewise, in departments where many of the experienced male students actively recruited, women's representation was lower than in departments where few male students actively recruited ($r = -.33$, significant at the .05 level). The stronger positive effect that recruiting by men faculty has on men students appears to advantage prospective male students over female students.

To accommodate the small number of cases in our data set, we performed a factor analysis and combined recruiting through personal contact by male faculty with recruiting by experienced male graduate students into one variable that represents personal recruiting by men in the department. This factor score variable had a moderate negative correlation with women's representation ($r = -.47$, significant at the .01 level. The factor loading was .65.) We used this combined variable in subsequent analyses.

Predicting the gender composition of enrollment.

Based on the preceding analyses, we can suggest some components of a linear model for predicting the gender composition of enrollment in CSE graduate programs. Our model is far from complete, but it is a good initial step toward measuring the effects certain department activities have on women's representation. Of all the recruitment and admission practices and student preferences we considered, it appears that departmental effort to enroll women, program flexibility, and recruiting by men have the strongest influence on gender balance. Results were similar whether limiting analysis to only those cases that put more than a little effort into recruiting women or using the full set of departments. Table 5 summarizes these results. The most notable difference between the two sets of results was that the negative effect of men recruiters is less for departments that put some effort into recruiting women.

Together, these factors account for 29 percent of the variance in women's representation in graduate CSE programs. As Table 5 shows, when all study departments are considered, both flexibility and effort to enroll women have a positive association with a department's percent of graduate students who are women (Beta=.21 and .29, respectively, significant at the .05 level), and recruiting by men has a negative association (Beta=-.49, significant at the .05 level.) When the regression includes only the subset of departments with a linear association with effort, the size of the effects differ somewhat, but all relationships are in the same direction.

Discussions and Conclusions

Computer science and computer engineering programs operate under special circumstances. They award credentials attesting to expertise in a field that our culture defines as appropriate for men (Charles & Bradley, forthcoming 2006). As a result of the gender typing of computing as masculine, practices that may be adequate for gender-balanced enrollment in the graduate programs of most disciplines are insufficient for creating gender balance in CSE. Nevertheless, this study demonstrates that it is possible to overcome the cultural beliefs and stereotypes that promote gender imbalance to some degree.

Our findings about effort suggest that an approach tailored to the conditions in individual departments may be necessary for achieving measurable differences in gender balance. Although reports of more than a little effort were associated with relatively higher women's representation, we could not identify particular efforts that were related to gender balance in the manner expected. Analysis using more sensitive methods might elicit such evidence, but it might also be the case that interventions require multi-faceted approaches, that interactions occur between effort and particular practices, or that effort expended by a designated person or subgroup is insufficient to counteract routine practice by the average faculty member in a department.

On the whole, men and women were attracted to computing graduate study and programs by the same features, with both sexes identifying the same conditions as most important. Interest and enjoyment of computing was the top reason both sexes decided to go to graduate school in CSE. Reputation, financial aid, research opportunities, and areas of specialization were the top influencers on choice of graduate program for both sexes. Male-female differences emerged primarily in strength of ratings. But among the factors that were rated differently by men and women, only flexibility in program content was significantly related to women's representation. The meaning and importance of flexibility is being further investigated in analyses currently underway, but it appears that this aspect of CSE graduate programs could contribute to attracting women into particular programs.

Experts and activists recommend particular practices for achieving gender balance in computing, but our research suggests that many recommended practices fail to have the desired effect, and some practices may even work against women's representation. In particular, personal recruiting is a highly recommended practice that our analysis calls into question. The CRA Best Practices (Cuny and Aspray, 2000) recommends being "proactive in making recruiting contacts" and calls for personalized contacts with prospective students, but our findings point to the critical role that implementation and motive might play. We found a moderately strong negative association between women's representation and recruiting by male faculty and students, so this action, as it is commonly practiced, seems to generally work against gender balance.

The negative relationship between women's representation and recruiting by men does not necessarily imply that we should abandon a behavior that practitioners strongly endorse. Active, personal recruiting was a positive factor that attracted many of the students who are currently enrolled in CSE graduate programs. Furthermore, faculty members have faith in the effectiveness of this practice. These realities should not be ignored by those who wish to create gender-balance in computing.

It is possible that personal recruiting by male faculty members is a powerful and effective tool that only increases women's representation under specific conditions. As is the case with mentoring CS undergraduates (Cohoon, Gonsoulin, & Layman, 2004), action with the intention to promote diversity might be a necessary component for positive effects on women's participation in computing. Even when faculty members are open to recruiting women, they may unconsciously underestimate women prospective students. This process is documented in many evaluation situations, including hiring at law firms (Gorman, 2005) and the peer review process in science (Wenneras & Wold, 1997), and it may be the reason women's representation is not higher when faculty members meet with prospective students. In other words, the purpose and skill with which a tool such as personal recruiting is used affects the results achieved.

Further research is needed to investigate whether personal recruiting yields higher female representation than an applicant pool would otherwise produce. But for now, we should consider a noteworthy implication of our recruitment findings – departments with the goal of adding women to achieve gender balance cannot afford to ignore gender. Being gender blind does not attract women into computing.

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APPENDIX A. Program Choice Factors Investigated

1. Institutional factors:

- a. Expense
- a. Availability of financial aid
- b. Geographic preferences or constraints
- c. Availability of course offerings during the academic year
- d. Courses offered at convenient times of day
- e. Flexibility in program content
- f. Reputation of institution
- g. Reputation of program or professor(s)
- h. Ability to pursue a particular computing specialization
- i. Teaching opportunities
- j. Research opportunities
- k. Facilities and equipment
- l. Departmental recruitment literature or webpage
- m. Size of institution
- n. Number of faculty in the program
- o. Employer tuition reimbursement program
- p. Earned prior degree from same institution
- q. Minimal academic or bureaucratic obstacles
- r. Please specify other important institutional factor(s):

2. Interpersonal factors:

- a. Opportunity to work with a particular research advisor
- b. Your impression of students during a campus visit
- c. Your impression of faculty during a campus visit
- d. Departmental culture
- e. Social atmosphere of the campus
- f. Presence of women students
- g. Presence of women faculty
- h. Prior enrollment of family or friend(s)
- i. Recommendation of faculty or mentor
- j. Faculty member's visit at your undergraduate department
- k. Phone call or mail from graduate faculty member(s)
- l. Please specify other important interpersonal factor(s):

Table 1 Factors that Influenced Choice of Program

Importance of Selected Factors Influencing Choice of Program, by sex		
	Male Mean Rating	Female Mean Rating
Institution reputation	3.9	3.9
Program or professor reputation	3.8	3.9
Financial aid available*	3.7	3.9
Research opportunities	3.8	3.7
Particular computing specialization*	3.6	3.7
Geographic preferences or constraints**	3.0	3.3
Impression of faculty from campus visit**	2.9	3.1
Department culture**	2.9	3.1
Flexibility in program content**	2.8	3.0

Ratings are on a scale where 1= not at all important and 5 = extremely important

*statistically significant at the .05 level

**statistically significant at the .01 level

Table 2 Recruitment and Admission Actions

Actions related to amount of effort expended for enrolling women		
	Mean frequency of action on 1-5 scale	Correlation with dept. mean effort to enroll women
Actively recruit from liberal arts colleges	1.89	.52**
Actively recruit from women's colleges	1.67	.43**
Admission criteria emphasized academic letters of recommendation	4.24	.41**
Meet prospective students	3.62	.33*
Involve undergraduates in my own research	3.52	.33*
Admission criteria emphasized maturity	3.42	.33*
Admission criteria emphasized undergrad degree from this institution	1.99	-.32*
Recruit through personal contacts in undergraduate depts.	2.61	.30*
Faculty actively recruit graduate students	3.08	.28*
Admission criteria emphasized research experience	3.82	.27*
Actively recruit at conferences	2.60	.26*
Admission criteria emphasized prior graduate degree	2.39	-.25*
*Significant at the .05 level. **Significant at the .01 level.		
Actions unrelated to amount of effort expended for enrolling women		
Teach summer research courses	1.41	.17
Sent personal letters/email to prospectives	3.21	.19
Presentations to cs/ce undergrads	2.72	.04
Personally call prospectives	2.63	.14
Encourage undergrads to go to grad school	4.17	.07
Encourage masters to go on to PhD	4.12	-.07
Assist students with grad applications	3.06	.20
Admission criteria emphasized students who desired to use tech skills for social good	2.36	.10
Admission criteria emphasized US citizenship	1.97	.01
Admission criteria emphasized undergrad computing degree	3.46	.12
Admission criteria emphasized reputation of undergrad program	3.95	-.07
Admission criteria emphasized quality of academic record	4.43	-.14
Admission criteria emphasized non-comp. work/volunteer experience	1.81	.14
Admission criteria emphasized motivation	4.25	-.01
Admission criteria emphasized member of underrepresented group	2.64	.22
Admission criteria emphasized Math background	3.81	-.07
Admission criteria emphasized leadership experience	2.54	.15
Admission criteria emphasized GRE score	3.55	.00
Admission criteria emphasized GRE CS subject exam score	2.72	-.10
Admission criteria emphasized grades in non-computing courses	3.09	.22
Admission criteria emphasized grades in computing courses	4.21	.22
Admission criteria emphasized gave special consideration to applicants away from formal education for a time	2.05	-.18
Admission criteria emphasized EE background	2.03	-.04
Admission criteria emphasized computing work/volunteer experience	2.66	-.09
Admission criteria emphasized computing experience	3.58	.11
Admission criteria emphasized communications skills	3.84	.20
Admission criteria emphasized area of research interest	3.49	-.08

Table 3 The Importance of Meeting Faculty

Correlations between Faculty Meeting Prospectives and Importance of Impression Made by Faculty			
	Mean frequency of faculty meeting with prospective students	Male faculty frequency of meeting with prospective students	Female faculty frequency of meeting with prospective students
Mean enrolled student importance of impression made by faculty	.70**	.70**	.43**
Male student importance of impression made by faculty	.69**	.63**	.48**
Female student importance of impression made by faculty	.43**	.53**	.16

* Correlation is significant at the .05 level (1-tailed).
 ** Correlation is significant at the .01 level (1-tailed).
 n=42 due to listwise deletion of missing cases. Similar results are obtained with pairwise deletion.

Table 4 The Importance of Student Recruiting

Correlations between Experienced Student Recruiters and Importance of Student Impressions		
	% of experienced female students who helped recruit	% of experienced male students who helped recruit
female first-year mean importance of student impression	.42**	.32*
male first-year mean importance of student impression	.41**	.36*

* Correlation is significant at the .05 level (1-tailed).
 ** Correlation is significant at the .01 level (1-tailed).
 n=38 due to listwise deletion of missing cases.

Table 5 Regression Results

Regression on Women's Representation in Graduate CSE Programs		
	Beta for all departments n=46	Beta for departments where effort >=2.6 n=34
Flexibility in program content	0.21*	0.18
Men recruiters	-0.49**	-0.35*
Effort to enroll women	0.29*	0.36*
Adjusted R ²	0.29**	0.29**

* Significant at .05 level.
 **Significant at .01 level.