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WOMEN IN GRADUATE ENGINEERING: IS DIFFERENTIAL DROPOUT A FACTOR IN THEIR UNDER REPRESENTATION AMONG ENGINEERING DOCTORATES?

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In the United States, women represent at most 20% of doctoral-level engineers. Differential dropout has been proposed as an explanation, but few studies have tested this theory for women in graduate engineering programs. Additionally, past research has not taken into consideration how the influx of foreign students into graduate engineering programs may affect women's proportionate enrollment and degree completion. To address these gaps, this study examined factors associated with enrollment and degree completion of female and male students (n = 470) in graduate engineering programs at a state university between 1990 and 2004. Women comprised 14% of graduate engineering students, but were as likely as men to complete doctoral degrees when factors associated with graduation (e.g., final GPA, engineering field) were considered. Among U.S. citizens, women had higher rates of degree completion than men, while the opposite was observed for foreign nationals. If replicated across institutions, these findings suggest that differential enrollment, not differential dropout, is the dominant factor in women's underrepresentation among engineering doctorates. This study's findings also point to the importance of examining the intersection of gender and culture to understand and support engineering educational choices, persistence, and success.

KEY WORDS: *women, engineering, doctorate, culture, gender, degree completion*

1. INTRODUCTION

In 2006, 20.2% of individuals earning doctoral degrees in engineering in the United States were women. Although this represents an impressive change from 30 years earlier when women received 1.9% of engineering doctoral degrees, it is far from the level of representation achieved by women in other historically male-dominated fields. For example, in the same time period, the proportion of women who earned doctoral degrees in the life sciences went from 20.1% to 51.6% (Ferreira, 2009). The underparticipation of women in engineering is a significant concern because it contributes to the already narrow pool and the limited diversity of individuals in U.S. engineering (National Academy of Sciences, National Academy of Engineering, & Institute of Medicine, 2007). Understanding the underrepresentation of women at higher levels of engineering education is essential if the United States is to maintain its visibility and leadership in engineering.

A common belief is that women drop out of doctoral engineering programs at higher rates than men (Wyer, 1997). This belief is based on observations of the progressively

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lower proportions of women at higher levels of engineering education, a phenomenon commonly referred to as the "leaky pipeline" (Berryman, 1983). For example, according to statistics from the U.S. Department of Education, in 1992–1993 women earned 15.8% of engineering undergraduate degrees, 14.8% of engineering master's degrees, and 9.6% of engineering doctoral degrees (Babco, 1994). Similarly, in 2003, the proportion of engineering degrees earned by women was 20.1, 21.9, and 17.3% at the undergraduate, master's, and doctoral levels, respectively (Babco & Bell, 2004).

Women's underrepresentation among engineering doctoral degree recipients, however, is not necessarily a sign of women's high dropout rates during graduate school (Wyer, 1997). It is equally possible that women choose not to enter engineering doctoral programs in the first place, perhaps because they prefer industry jobs that only require a master's degree. In other words, the theory that higher graduate school attrition rates by women are responsible for women's underrepresentation among doctoral degree recipients requires verification.

The few studies that compared doctoral degree completion by men and women enrolled in graduate engineering programs have yielded mixed results. A study conducted at the University of California, Berkeley, and covering the period 1978 to 1979, found that women completed doctoral degrees in science and engineering at frequencies over 10% lower than men (Sherry & Dix, 1992). By contrast, a study of National Science Foundation fellowship applicants from 1972 to 1981 who completed their doctoral degrees by 1988 found that, after controlling for academic potential (based on GRE test scores, undergraduate GPA, research proposal, and letters of recommendation) and fellowship receipt, women in engineering, mathematics, and physical science doctoral programs had only slightly lower degree completion rates than men (Baker, 1998). Another study reported no significant differences in the proportion of women and men completing master's or doctoral engineering degrees at North Carolina State University in the 1980s (Wyer, 1997).

A limitation of past research on women's engineering doctoral degree completion is that it has generally not considered differences by field. This is an important omission because women's enrollment varies widely depending on engineering field. In the four largest fields of engineering (chemical, civil, electrical, and mechanical), chemical engineering has historically shown a greater proportionate representation of female doctoral students than other engineering fields. For example, a 1992 summary of national data by the Commission on Professionals in Science and Technology (Vetter, 1994) found that chemical engineering had the highest proportion of women earning doctoral degrees (16.5%), followed by civil (6.7%) and mechanical (3.9%). Data were not available on electrical engineering. Similarly, in 2006 the proportion of women earning doctoral degrees in these four engineering fields was highest for chemical engineering (25.9%), followed by civil (21.9%), electrical (14.9%), and mechanical engineering (13.9%) (Ferreira, 2009). Women in more strongly male-dominated fields of engineering may face additional challenges that likely affect their probability of degree completion. Findings related to degree completion in one field of engineering may therefore not be generalized to other engineering fields, and summary statistics that combine all fields may present a misleading picture.

Another limitation of past research is that it did not assess the national origin of engineering graduate students. The commonly used metaphor of the leaky pipeline is based on the assumption that we are observing a gradual loss of women from a single pool of potential future engineers. This assumption is misleading with respect to U.S. graduate engineering because of the large influx of foreign nationals into graduate engineering programs. Data from a survey of earned doctorates showed that, from 1973 to 2003, the proportion of engineering doctoral recipients who were not U.S. citizens was 50–60% (Hoffer et al., 2004). This large influx of foreign students in the U.S. graduate engineering pipeline may carry with it a new sex ratio. A study of the proportion of women earning engineering doctoral degrees in different countries found a wide range of values. Taiwan had the lowest (2%), and Kyrgyzstan the highest (46%) representation of women, with the United States falling in the middle of the range (17%) (Babco & Bell, 2004). These data suggest that factors related to country of origin could have an important influence on women's choice of, and persistence in engineering higher education. Despite such findings, the impact of the high proportion of foreign nationals in U.S. engineering graduate education has rarely been considered in studies of women in U.S. engineering graduate education. However, studying women in U.S. graduate engineering without regard to their nationality may obscure important cultural patterns. For example, given that over 50% of engineering graduate students are foreign nationals, an increase in the representation of women among foreign national graduate students could partially account for the documented growing proportion of women in U.S. graduate engineering schools. That is to say, given that fewer U.S. citizens are in graduate engineering school, the proportion of the graduate engineering population consisting of women could be strongly influenced by foreign national students' female-male ratio rather than by a U.S. female-male ratio change. This is exactly what a recent study documented. Specifically, from 1996 to 2006, the percentage of engineering doctorates awarded by U.S. institutions to foreign national women increased, while the percentage of engineering doctorates awarded to U.S. women decreased slightly (Ferreira, 2009).

This current study focused on women in graduate engineering programs, an understudied group with regard to leaky pipeline questions. It sought to examine women's progress in graduate engineering, from enrollment to degree completion, in light of important but previously neglected factors, such as field of engineering and country of origin. This study also built on previous studies by assessing factors (such as marital status) found to influence women's educational choices and success in engineering.

This study's first set of research questions pertains to the demographic profiles (e.g., nationality, marital status) of women enrolled in U.S. doctoral engineering programs. Based on previous studies (Hoffer et al., 2004; Vetter, 1994), we expected differing levels of enrollment by women depending on engineering field. Specifically, we predicted that women's enrollment would be highest in chemical and civil engineering, and lowest in electrical and mechanical engineering (Hoffer et al., 2004; Vetter, 1994). On the basis of previous findings (Babco & Bell, 2004), we also anticipated differing levels of enrollment by women depending on their national origin.

Our second set of research questions focused on degree completion, specifically on the theory that women are more likely to drop out of engineering doctoral programs than men. Because of the variability in the proportion of women earning engineering doctoral degrees in different countries (Babco & Bell, 2004), we also examined whether degree completion would differ for students from different countries. Furthermore, consistent with studies of undergraduate engineering degree completion (e.g., Ohland et al., 2008;

Zhang, Anderson, Ohland, & Thorndike, 2004), we evaluated graduate degree completion rates depending on factors such as ethnicity, department, citizenship, term of first enrollment, final GPA, age at first enrollment, and marital status. Finally, based on past evidence that family relationships typically contribute more demands than resources to women's professional development (Frome, Alfeld, Eccles, & Barber, 2006; Grant, Kennelly, & Ward, 2000; Mason & Goulden, 2004; Xie & Shauman, 2003), we expected lower proportions of married women to complete their doctoral degrees, compared to single women.

2. METHOD

2.1 Procedures

Information about graduate students in engineering departments at Colorado State University (CSU) for the time period beginning in the fall of 1990 and ending in the fall of 2005 was obtained from the Office of Budgetary and Institutional Analysis (OBIA). CSU was a good fit for this study because of its well-established, large engineering college. Data were available on the department and type of program that students were enrolled in (master's versus doctoral), as well as students' sex, marital status, ethnicity, country of origin, age, and graduate GPA, for every term in which students were enrolled until they graduated or left the program without a degree. Students were identified by a random numerical code. Data manipulations in preparation for statistical analysis were performed using either Excel (2000) or SAS (version 9) software programs.

Because we only wanted to include data about students for whom we knew both start and end term (i.e., the term in which they were first enrolled and the term in which they either dropped out or completed a degree), we excluded from analyses data on students whose status was not "new student" in the first term for which we had data. We also removed information about students who were still enrolled during any semester of 2005. Removing these data reduced our sample size and resulted in the exclusion of data on some students who were genuine dropouts or who completed degrees, but also eliminated the possibility that students who were taking a semester or a year's leave of absence would be counted as dropouts. Our final sample, after eliminating all students enrolled in any term of 2005, comprised 470 doctoral engineering students.

2.2 Categorization of Variables

The majority of variables were categorical. Due to the very low number of individuals in ethnicity categories other than "white, non-Hispanic" we simplified this variable to create three groups, namely, (i) white non-Hispanic, (ii) nonwhite (this includes individuals who self-identified as Asian/Pacific Islander, black non-Hispanic, Hispanic, or mixed), and (iii) not reported. Similarly, we classified students' countries of origin into eight world geographic regions, namely, (i) Africa, (ii) East Asia, (iii) Europe (Eastern and Western), (iv) Middle East, (v) South and Central America, (vi) South and Southeastern Asia, (vii) United States, and (viii) other or not Reported. For some statistical analyses, these regions were combined into two citizenship categories (United States and foreign national). Data on GPA, start age, and start term (the semester and year in which a student first enrolled) were also treated as categorical variables because they did not meet the assumption of linearity in the logit model (Hosmer & Lemeshow, 2000). We assigned categorical cutoff points to GPA according to the standard letter grades cut offs (i.e., A− = 3.7, B+ = 3.3). For students' starting age, we examined the sample's age distribution and then divided starting age into two categories, using the median age (29 years) as the categorical cutoff point. To examine the question of whether start date affected the probability of degree completion, only the data from students belonging to cohorts that had a reasonable amount of time to complete their degrees were analyzed. To determine what terms to include in each time category, we calculated the mean and standard deviation for the amount of time required for doctoral degree completion (14 terms ± 6 terms). We then placed all students with start terms in the last 20 terms of data collection (fall 1998–summer 2004) into one data category, and considered this category as uninterpretable in terms of how changes over time might have affected completion rate, because these students might not have had sufficient time to complete a degree. Students in the remaining terms were assumed to have had ample time to complete a degree. These terms were therefore divided evenly into thirds, and the resultant four categories (three interpretable and one uninterpretable) were used in the statistical analyses.

2.3 Statistical Analyses for Enrollment

Binary logistic regression analyses were used to test whether ethnicity, department, world geographic region, start term, final GPA, start age, and relationship status predicted women's enrollment, as compared to men's enrollment. For each independent variable included in the logistic regression analysis, we assigned the reference group according to the following criteria. For the variables sex, ethnicity, GPA, and world geographic region, we chose the categories with the largest student representation (male, white, GPA ≥ 3.7, and United States, respectively) to serve as a basis for comparison with the other categories. For the department variable, we chose the category with the lowest female enrollment (electrical engineering). The first start term category for which we had data (fall 1990–spring 1993) was used as the reference group. Finally, a start age of <29 and a relationship status of "start single, end single" were chosen as the reference groups for these variables because these categories could be considered an initial developmental stage.

Following the model building procedure recommended by Hosmer and Lemeshow (2000), we conducted univariate chi-squared analyses on all variables associated with degree completion. Eight variables were included in these initial analyses, namely, sex, ethnicity, department, world geographic region of origin, age at first enrollment, term of first enrollment, GPA during the student's final term of enrollment, and change in relationship status. Any variable whose univariate test resulted in a p value of <0.25 was selected for inclusion in the initial multivariate models. Use of more stringent selection criteria at this stage (e.g., a selection criterion of $p < 0.05$) can result in the exclusion of variables that are actually important to the model. The exception was student sex, which, as a variable of primary interest, was included in the model regardless of the results of the univariate analysis. Because we were interested in how women's and men's enrollment might vary based on country of origin, this variable included eight geographic regions. Some of these regions had few cases, particularly among women. It was not possible to include interaction terms in this logistic regression analysis and still have model convergence, so only main effects were included. To produce the final model, nonsignificant main effects were removed one at a time, starting with the variable with the highest p value on chi-squared likelihood ratio tests. The model was examined after the removal of any variable for large changes in other variables, which could indicate that the excluded variable was important because it adjusted the effect of another variable. Removal continued until the model contained only variables whose chi-squared likelihood ratio p value was less than .05, or whose odds ratio parameter estimates indicated that at least one category differed significantly from the reference group.

2.4 Statistical Analyses for Degree Completion

We used binary logistic regression analyses to examine factors associated with doctoral degree completion. The initial model building process was the same as for the enrollment analyses, with two exceptions. For degree completion, we used civil engineering as the reference group because this was the department in which the largest proportion of students completed their doctoral degrees. In addition, we included the citizenship variable (instead of the world geographic region of origin variable) because in this analysis we were more interested in examining interactions between sex of respondent and other variables than in geographic variations. Once the variables to be included in the preliminary model were determined using univariate analyses, we added each of the possible interaction terms between sex of respondent and the other variables one at a time (Hosmer & Lemeshow, 2000). All interactions found to be significant following this method were then simultaneously added back to the model. To produce the final model, any main effects that were not significant in the model and that were not part of any significant interaction term were removed one at a time, following the removal criteria described previously.

Finally, following this same logistic regression procedure, we examined the subset of data comprised of individuals who completed a master's degree in engineering at CSU before entering into a doctoral engineering program to see whether the previously formed model was robust with a selected population. Three modifications were made in these analyses. First, we combined the two lowest GPA categories into a single "<3.7 GPA" category because in this smaller sample there were very few women in the lowest GPA category. Second, we included a new continuous variable, time to complete master's degree. Finally, because for this data set we had information on start term, start age, end GPA, and relationship status change for an individual's time as a master's and as a doctoral student, we ran univariate analyses on the master's as well as the doctoral data for these variables. To avoid the inclusion of intercorrelated data, only one of the two sets of values was included in the logistic regression model. We included masters' start date, rather than doctoral program start date, because the former indicates when individuals started their graduate training. In addition, we used GPA at the end of the doctoral program as indicator of overall grade success. Finally, we included change in relationship status during the doctoral program because univariate analysis of relationship status during the master's degree program did not show a significant effect on doctoral degree completion.

2.5 Assessing Model Fit

The final model fit was assessed using a deviance chi-squared test. The goodness of fit test compares the model to a saturated model, with a large p value indicating that the two models are similar and the model therefore is a good fit to the data. The overall predictive ability of the model was tested using a model fit chi-squared test. A p value of <0.05 on this test indicates that the model explains significantly more of the variance in the data set than would be explained without the model. Finally, a Nagelkerke pseudo-R^2 statistic, i.e., a measure of the strength of the relationship between the dependent variable and independent variables, was calculated (Norusis, 2005).

3. RESULTS

3.1 Enrollment

From 1990 through 2004, there were 470 students with known outcomes (dropped out or obtained a doctorate) enrolled in doctoral engineering programs at the target university. Sixty-five of these 470 students (13.8%) were women. Women represented 13.3% and 14.3% of U.S. and foreign national graduate engineering students, respectively. Table 1 compares the ethnicity, department, world region, start term, final GPA, start age, and relationship status of the women and men enrolled in these programs from 1990 to 2004. The final logistic regression model included department, world region, start term, and start age as predictors of the sex of students enrolled in engineering doctoral programs (Table 2). World region was included in the model even though its chi-squared likelihood ratio p value was only marginally significant ($\chi^2 = 12.48$, $df = 7$, $p = 0.09$) because it was a variable of theoretical importance in this study. Deviance chi-squared analysis indicated that, overall, the model was a good fit to the data ($\chi^2 = 112.00$, $df = 119$, $p = 0.66$), although it explained a relatively small proportion of the variance in the dependent variable (Nagelkerke pseudo $R^2 = 0.15$).

Examination of this model showed that the department of electrical engineering had the smallest proportion of female doctoral students. The proportionate enrollment of women in the department of mechanical engineering did not differ significantly from that of women in electrical engineering; that is, women were equally underrepresented in both departments. However, women were significantly more likely to enroll in chemical than in electrical engineering. There was also a trend toward higher female enrollment in civil engineering compared to the reference group of electrical engineering.

The model showed no significant female enrollment differences across the seven foreign geographic categories examined, compared to the United States. However, there was a trend ($p < 0.10$) toward higher female representation among engineering students from South or Central America (26.7% female, $n = 15$) and engineering students from South or Southeast Asia (25.9% female, $n = 27$), compared to engineering students from the U.S. (13.3% female, total $n = 226$) (see Table 2).

The model also showed that students who started their degree program between spring 1996 and summer 1998 (the third time category) and between fall 1998 and fall 2004 (the last time category) were significantly more likely to be female than students

TABLE 1: Descriptive statistics on enrollment in doctoral engineering programs, 1990–2004

		Number of students			
Variable category		**Female**	**Male**	**Total**	**% female**
Ethnicity					
	Nonwhite	2	27	29	6.9
	White*	26	148	174	14.9
	Not available	37	230	267	13.9
Engineering department					
	Mechanical	9	79	88	10.2
	Chemical	17	43	60	28.3
	Electrical	12	119	131	9.2
	Civil*	27	164	191	14.1
Citizenship					
	Foreign national	35	209	244	14.3
	United States*	30	196	226	13.3
World region					
	Africa	1	22	23	4.3
	East Asia	16	86	102	15.7
	Europe	3	14	17	17.6
	Middle East	1	39	40	2.5
	South/Central America	4	11	15	26.7
	South/Southeast Asia	7	20	27	25.9
	Not available/miscellanea	3	17	20	15.0
	United States*	30	196	226	13.3
Start date					
	Fall 1990–spring 1993*	7	97	104	6.7
	Summer 1993–Fall 1995	17	112	129	13.2
	Spring 1996–summer 1998	16	77	93	17.2
	Fall 1998–summer 2004	25	119	144	17.4
Final GPA					
	<3.3	3	35	38	7.9
	≥3.3	16	117	133	12.0
	≥3.7*	38	208	246	15.4
	Unknown	8	45	53	15.1
Start age					
	≥29 years	26	244	270	9.6
	<29*	39	161	200	19.5
Marital status					
	Started married, ended married	23	180	203	11.3
	Started single, ended married	7	40	47	14.9
	Started married, ended single	1	8	9	11.1
	Started single, ended single*	32	123	155	20.6

Note: Asterisks (*) indicate the reference group in subsequent logistic regression analyses.

TABLE 2: Final model of logistic regression analysis for women's and men's enrollment

Variable name		OR	95% CI	*p*
Engineering department				
	Mechanical	1.06	0.41–2.79	0.90
	Chemical	3.51	1.48–8.35	0.004
	Civil	1.90	0.88–4.10	0.10
	Electrical	Reference		
World geographic region				
	Africa	0.45	0.06–3.65	0.45
	East Asia	1.11	0.55–2.25	0.77
	Europe	1.31	0.34–5.14	0.70
	Middle East	0.15	0.02–1.13	0.07
	South/Central America	3.04	0.85–10.86	0.09
	South/Southeast Asia	1.95	0.71–5.36	0.19
	Not available/miscellanea	1.44	0.37–5.63	0.61
	United States	Reference		
Start term				
	Fall 1990–spring 1993	Reference		
	Summer 1993–fall 1995	2.56	0.98–6.72	0.06
	Spring 1996–summer 1998	3.29	1.22–8.84	0.02
	Fall 1998–summer 2004	3.88	1.52–9.93	0.005
Start age				
	≥29	0.44	0.25–0.78	0.005
	<29	Reference		

Note: Model fit $\chi^2 = 41.82$, $df = 14$, $p < 0.0005$. OR = odds ratio; CI = confidence interval. A confidence interval greater than one indicates a significantly higher female enrollment, compared to the reference group.

who started in the first time period for which we had data (fall 1990 to spring 1993). The second time category (summer 1993 to fall 1995) also showed a trend toward increased female representation, compared to the first, although the difference was not significant ($p = 0.06$; see Table 2). These trends give the impression that there was a growth in female enrollment through our observation period. However, an examination of annual changes in the proportionate representation of women indicates that changes in enrollment patterns were complex, with a dramatic decline in female enrollment in 2000, and inconsistent patterns of female enrollment since that time.

Finally, the model indicated that there was a significant difference between the age of female and male students at doctoral program enrollment time. Students who were 29 years old or older at time of enrollment were significantly more likely to be male than female.

3.2 Degree Completion

Summary information comparing the sex, ethnicity, department, citizenship, world geographic region of origin, start term, final GPA, start age, and relationship status of students who dropped out of the doctoral program as compared to students who obtained a doctoral degree is presented in Table 3. There was no significant difference between women and men in the likelihood of degree completion, when controlling for factors associated with degree completion (see Table 4). The final logistic regression model after elimination of nonsignificant variables (i.e., department, ethnicity, and age at the time of enrollment) indicates that start term, final GPA, citizenship, and relationship status were all significant predictors of degree completion. There was also a significant interaction between sex and citizenship, with women having higher degree completion rates than men among U.S. citizens, while the opposite pattern was observed for foreign nationals (see Table 4). Deviance chi-squared analysis indicated that, overall, the model was a good fit to the data ($\chi^2 = 118.82$, $df = 120$, $p = 0.51$), with a Nagelkerke pseudo-R^2 value of 0.36. Specifically, the model showed that foreign students were significantly more likely to earn doctoral degrees than students from the United States. There was variability across world regions in the proportion of students earning degrees, but every geographic region (with the exception of the no response/miscellaneous category, which consisted mostly of students whose country of origin was unknown, but also included students from countries with very small sample sizes) had higher earned doctorate percentages than the United States. Among U.S. students, a higher proportion of women completed degrees than men, while the opposite trend was observed for foreign nationals (see Fig. 1). Examination of this relationship with foreign nationals subdivided by world geographic regions indicates that this was a fairly consistent pattern, with a higher proportion of U.S. women completing degrees than women from six of the seven foreign world regions. The mean final GPA for this graduate student sample was 3.70. Final GPA was a significant predictor of degree attainment, with students whose GPAs was below 3.30 being significantly less likely to attain degrees than students in the reference group, with GPAs ≥ 3.70.

Examination of the relationship between marital status and degree completion showed that students who identified as married in both the first and last terms for which we had demographic and enrollment data were significantly more likely to complete a degree than students who self-identified as single at both of these time points. Individuals who underwent a change in relationship status (i.e., who either got married or divorced while in graduate school) were also significantly more likely to complete their doctoral degrees than students who were single at both the beginning and end of their enrollment.

Finally, students who started their degree program between spring 1996 and summer 1998 (the third time category) were significantly less likely to complete a doctoral degree than students who started in the first time period in this study, that is, fall 1990 to spring 1993. No such pattern was observed for students in the second time category (summer 1993 to fall 1995). Students in the most recent enrollment time category (fall 1998 to fall 2004) had significantly lower degree completion rates than students who started in the first time period.

A second logistic regression model predicting the likelihood of doctoral degree completion for the subset of students who completed a master's degree ($n = 145$) yielded similar results to those obtained for the sample as a whole ($n = 470$). The final logistic regression model, after elimination of nonsignificant variables and the addition of interaction terms, again indicated that there was no significant difference between men and women in the likelihood of degree completion when controlling for factors associated with degree completion. Master's start term, final GPA, relationship status, and time to earn master's degree were all significant predictors of degree completion. Citizen-

TABLE 3: Descriptive statistics on degree completion for doctoral engineering students, 1990–2004

		Number of students			
Variable category		**No Ph.D.**	**Ph.D.**	**Total**	**% Ph.D.**
Sex					
	Female	38	27	65	41.5
	Male*	205	200	405	49.4
Ethnicity					
	Nonwhite	16	13	29	44.8
	White*	97	77	174	44.3
	Not available	130	137	267	51.3
Engineering Department					
	Mechanical	52	36	88	40.9
	Chemical	31	29	60	43.5
	Electrical	74	57	131	43.5
	Civil*	86	105	191	55.0
Citizenship					
	Foreign national	114	130	244	53.3
	United States*	129	97	226	42.9
World geographic region[a]					
	Africa	7	16	23	69.6
	East Asia	54	48	102	47.1
	Europe	7	10	17	58.8
	Middle East	14	26	40	65.0
	South/Central America	5	10	15	66.7
	South/Southeast Asia	12	15	27	55.6
	Not available/miscellanea	15	5	20	25.0
	United States*	129	97	226	42.9
Start term					
	Fall 1990–spring 1993*	45	59	104	56.7
	Summer 1993–fall 1995	46	83	129	64.3
	Spring 1996–summer 1998	50	43	93	46.2
	Fall 1998–summer 2004	102	42	144	29.2
Final GPA					
	<3.3	32	6	38	15.8
	≥3.3	63	70	133	52.6
	≥3.7*	98	148	246	60.2
	Unknown	50	3	53	5.7
Start age					
	≥29 years	138	132	270	48.9
	<29*	105	95	200	47.5
Marital status					
	Started married, ended married	95	108	203	53.2
	Started single, ended married	11	37	48	77.1
	Started married, ended single[b]	3	5	8	62.7
	Started single, ended single*	98	57	155	36.8
	Unknown	36	20	56	35.7

Note: Asterisks (*) indicate the reference group in subsequent logistic regression analyses. [a]Because classification of students according to world region resulted in small sample sizes for many regions, the general "citizenship" category was used in statistical analyses. [b]Because of the small sample size in the "start married, end single" (divorced) group, this category was combined with the "start single, end married" group (marital status changes) for statistical analyses.

TABLE 4: Final model of logistic regression analysis for variables affecting doctorate completion

Variable name		OR	95% CI	*p*
Sex				
	Female	2.20	0.85–5.70	0.11
	Male	Reference		
Citizenship				
	Foreign National	1.98	1.25–3.37	0.004
	United States	Reference		
Start term				
	Fall 1990–spring 1993	Reference		
	Summer 1993–fall 1995	0.90	0.48–1.69	0.73
	Spring 1996–summer 1998	0.42	0.22–0.82	0.01
	Fall 1998–summer 2004	0.26	0.14–0.42	<0.0005
Final GPA				
	<3.3	0.10	0.04–0.27	<0.0005
	≥3.3	0.73	0.46–1.73	0.20
	≥3.7		Reference	
	Unknown	0.04	0.01–0.26	<0.0005
Marital status				
	Start married, end married	1.88	1.16–3.05	0.01
	Change in marital status	5.15	2.39–11.08	<0.0005
	Start single, end single	Reference		
	Unknown	1.32	0.59–2.96	0.50
Sex of student, citizenship				
	Female, Foreign National	0.15	0.04–0.53	0.003
	Female, United States	Reference		

Note: Model fit $\chi^2 = 145.2$, $df = 12$, $p < 0.0005$. OR = odds ratio; CI = confidence interval.

ship was not a significant predictor ($p = 0.06$) for the master's sample. The interaction between sex of respondent and citizenship was also not significant ($p = 0.06$). The one new predictor variable, i.e., time to earn a master's degree, showed that individuals who took less time to complete their master's degree before enrolling in a doctoral program in engineering at CSU were significantly more likely to complete a doctorate than those who took longer.

4. DISCUSSION

This study focused on women's underrepresentation in engineering via an analysis of factors associated with women's enrollment in, and graduation from, doctoral engineer-

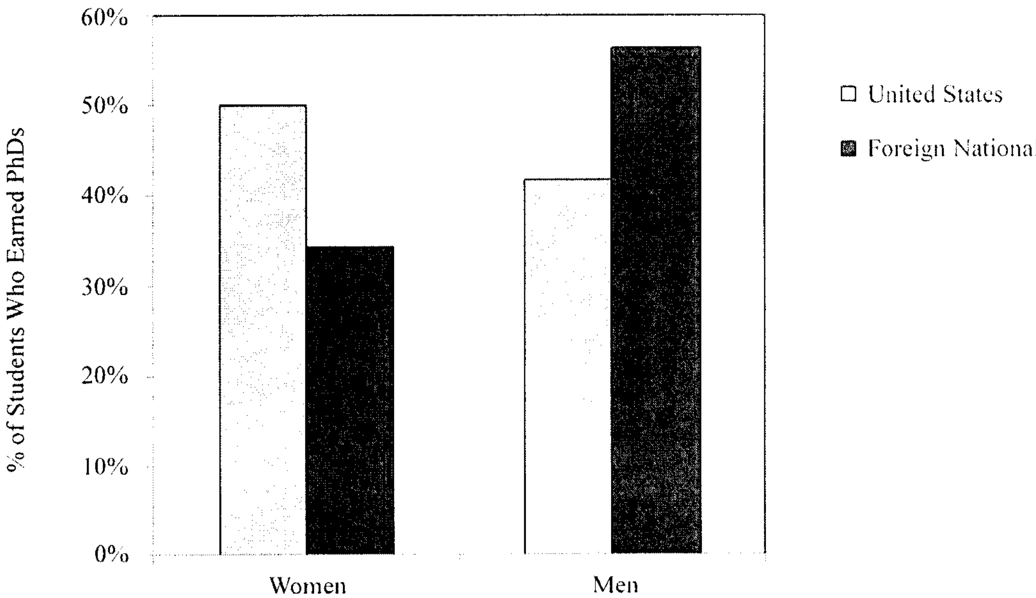

FIG 1: Sex of student by citizenship interaction effect in degree completion. Among U.S. citizens, a larger percentage of women than men completed doctoral engineering degrees, while the opposite was observed among foreign students.

ing programs—an understudied perspective. Before interpreting its findings, it is important to consider the study's strengths and limitation. Among the strengths are that this study included a 15-year span of data, and that it examined important heretofore overlooked variables, such as student nationality. A limitation of this study is that its data came from a single institution. Studies of undergraduate engineering indicate that undergraduate graduation patterns, and some of the factors associated with undergraduate graduation, vary by institution (Ohland et al., 2008; Zhang et al., 2004). Another limitation of this study is that the archival data we accessed had information in a restricted range of categories. Furthermore, the information that was available was often lacking in important details. For example, in this study we could identify an individual's marital status but had data neither about committed relationships other than marriage nor about parental status. With these caveats, we now discuss the main findings of the study.

4.1 Enrollment

The low (13.8%) proportionate enrollment of women in this study's graduate engineering sample is consistent with published national statistics (Bell, Di Fabio, & Frehill, 2006). When broken down by engineering department, this study's enrollment findings are also similar to the results of previous nationwide studies (Hoffer et al., 2004; Vetter, 1994), with electrical and mechanical engineering having the lowest proportions of women enrolled in doctoral programs (9.2% and 10.2%, respectively, in this study), and chemical engineering showing the highest proportion of women (28.3% in this study). When examined longitudinally, our data paint a sobering picture of women's participation in graduate engineering. Although higher levels of female enrollment were recorded in the early 2000s than at the beginning of the 1990s, examination of year-to-year trends showed no steady increase in female enrollment over time. Rather, there appears to have been a fairly steady pattern of increased female enrollment from 1990 to 1996, after which time enrollment patterns became quite unpredictable. This study's enrollment patterns over time are consistent with national data showing slow increases and erratic changes in the proportion of female engineering students (Hersh, 2000). The uneven growth in the representation of women in doctoral engineering programs, in contrast to the sustained growth of their participation in some other STEM disciplines, remains unexplained.

In addition to departmental and temporal enrollment patterns, two other factors emerged as potentially important in women's enrollment in doctoral engineering programs, namely, student's world region of origin and age at time of enrollment. Interpretation of the role of world provenience on the female-male ratio within doctoral engineering programs is not feasible based on our data. In our study, small sample sizes of many of the world regions data did not allow for statistical analyses of this factor. In general, variations in international women's enrollment patterns likely reflect a broad range of factors, from differences in attitudes toward women going abroad to study, to differences in the types of agreements the United States has with various countries in terms of the ease of getting foreign student visas, to differences in universities' international recruiting focus. This study's data indicate a trend toward higher female representation from certain regions, specifically, South/Central America and South/Southeast Asia. Future studies should seek to establish the generalizability of this study's findings. It will also be helpful to explore and understand the role that cultural attitudes toward female engineers may play in women's participation in doctoral engineering.

Women older than 29 years of age were significantly less likely to be enrolled in doctoral programs than men in this age category. The meaning of this finding depends largely on the reasons behind this age difference. It is possible that women older than age 29 encounter greater barriers to beginning a graduate program than women in their twenties. Perhaps women who take time off after completing their undergraduate degrees are less likely to start graduate studies because they have assumed family responsibilities. Studies found that when women marry or have children, they have difficulties finding the time and energy to pursue educational or career paths due to social expectations that they accommodate to their husbands' educational and work priorities, and that they take primary responsibility for household and child care duties (Frome et al., 2006; Grant et al., 2000; Mason & Goulden, 2004; Xie & Shauman, 2003). Further research is needed to explore whether this study's female-male differences in age of enrollment in graduate school are replicated with other samples. It will also be important for future research to track the career trajectories of women who complete undergraduate engineering degrees but do not go to graduate school in order to determine whether these women enter engineering-related jobs that do not require a post-baccalaureate degree, or leave the field altogether.

4.2 Degree Completion

In this study, women were as likely as men to complete their doctoral engineering degrees. If anything, women in our sample had a higher likelihood of degree completion than men (odds ratio = 2.20), although this difference was not significant because of a wide confidence interval (odds ratios of 0.85–5.70). The finding that women were not more likely than men to drop out of graduate school is consistent with the results of two prior graduate engineering retention studies (Nettles & Millett, 2006; Wyer, 1997) as well as the results of undergraduate engineering retention studies (Ohland et al., 2008; Zhang et al., 2004).

Contrary to expectation, degree completion did not vary significantly by engineering department. This finding suggests that women's underrepresentation in engineering, and particularly in some fields of engineering (e.g., mechanical, electrical), is driven by low enrollment rather than by low retention. Interventions to increase women's participation in engineering should therefore address recruitment, and especially focus on generating and sustaining women's interest in engineering fields with the lowest female representation.

This study's degree completion patterns are difficult to interpret when both students' sex and country of origin are taken into account. On the one hand, foreign national students were more likely to earn doctoral degrees than U.S students, a pattern driven by the fact that over 85% of our sample was male. On the other hand, foreign national women (with the exception of women from South and Central America) were less likely to complete their doctoral degree than U.S. women, while the opposite was true for men. The importance of considering nationality when interpreting data on women's representation in graduate engineering is also highlighted by the findings of a recent cross-sectional study of doctoral degree completion in U.S. programs (Ferreira, 2009). This study documented an increase, from 1996 to 2006, in the representation of foreign national women, but a slight decrease in the representation of U.S. women among the engineering doctorates. Ferreira's study did not include enrollment and retention information. Thus, it is unclear whether her findings reflect differences in initial enrollment and/or differences in degree completion. A limitation in both the present study and Ferreira's study is that both put all foreign national women in one group, to be compared with U.S. women. This kind of grouping, while sometimes necessary because of small sample sizes, obscures important cultural variability. Therefore, together, Ferreira's and our findings call for national-level analysis of the representation and experiences of women in graduate engineering.

In this study, staying married was associated with a higher likelihood of finishing the doctoral degree than staying single, and for both women and men. A caveat in the interpretation of this finding is that this study's data, including information about relationship status, came from official university records. It is possible that individuals in a long-term committed, cohabiting relationship were classified as single although they were functionally similar to married individuals. Taken at face value, this study's findings are consistent with those of Nettles and Millett (2006), who found that being married was associated with higher persistence in doctoral programs. It is noteworthy, however, that Nettles and Millett also observed that having children under the age of 18 was associated with women taking time away from the program. It is therefore possible that the positive role of marriage for women extends only to women without children. Previous research found that although many women and men have both career and family roles, only women in both roles typically work a second shift (e.g., Stevens Kiger, & Riley, 2001). Studies of women who complete their doctoral degrees have shown that having young children negatively affects their career advancement, while the opposite effect is found for men (Mason & Goulden, 2004; Xie & Shauman, 2003). We could not test this hypothesis in this study because the records accessed did not provide information on parental status. Future research might explore the role of marriage and parenting in women's and men's engineering educational and career attainments.

5. CONCLUSIONS AND IMPLICATIONS

This study addressed significant gaps in the literature on women in engineering higher education by evaluating factors associated with women's enrollment in, and graduation from, doctoral engineering programs, and with attention to students' nationality. We found that, in the target institution, women represented only 14% of students enrolled in graduate engineering, but also that women who started graduate training were as successful as men at completing their engineering doctorates. Our findings challenge the long-held assumption that women drop out of engineering at higher rates than men. This study's female doctoral degree completion findings are consistent with the results of recent studies of women's persistence in (Lord et al., 2009), and graduation from, undergraduate engineering programs (Ohland et al., 2008; Zhang et al., 2004). Overall, the evidence that women, at both the undergraduate and the graduate level, have lower enrollment rates than men but similar graduation success suggests that a most substantive factor in women's underrepresentation in engineering is recruitment. Our unexpected findings on marital status require investigation on how marriage and being a parent may impact the academic experiences and choices of women and men in graduate engineering. Also calling for verification and extension via multi-institutional research is our observation that female-male patterns of graduate enrollment and degree completion varied according to students' world region of origin. With regard to implications, this study's findings point to the importance of understanding the intersection of gender with other socially meaningful statuses (e.g., marital status) and experiences (e.g., nationality) to make sense of and support women's and men's engineering educational choices, persistence, and success.

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