Representation of Women in Postsecondary Computing: Disciplinary, Institutional, and Individual Characteristics

Stuart H. Zweben | The Ohio State University
Elizabeth B. Bizot | Computing Research Association

The results of an in-depth study of two decades of data from the Integrated Postsecondary Education Data System database highlight trends in the participation of women in postsecondary academic computing programs at the bachelor's, master's, and doctoral levels.

It has long been the case, and widely known, that women comprise a disproportionally low percentage of the students in postsecondary academic computing programs at all degree levels. But if we look more closely at the situation, we find that there are many things that we don't know about women's representation. Are there differences among the different disciplines within the computing field? Are there differences based on the type of institution in which the program is located, or based on women's ethnicity or citizenship? To what extent do these factors interact with each other? The purpose of this article is to take a systematic look "under the hood" at the details of women's degree attainment in computing from 1990 to 2013.

Data Source and Study Boundaries

We're responsible for the Computing Research Association (CRA) Taulbee Survey, conducted annually and often cited as a source of data on diversity in the field. Taulbee's focus, however, is the PhD-granting departments of computing. Because more than half of BS and MS degrees are granted by nondoctoral institutions, Taulbee doesn't have the scope for our desired systematic look across subdiscipline, institutional, and

 1521-9615/16/$33.00 © 2016 IEEE Copublished by the IEEE CS and the AIP

Conventional wisdom is that research institutions provide more access to cutting-edge science, but nonresearch institutions, which tend to be smaller, provide a more supportive environment, which could be especially significant for members of underrepresented groups.

individual characteristics. A new survey that collects data similar to Taulbee, called the NDC survey because it surveys non-doctoral-granting departments in computing, was initiated recently by the Association for Computing Machinery (ACM).[1] Because this survey is only in its third year of operation, there's insufficient data for meaningful trend analysis.

This article uses data from the Integrated Postsecondary Education Data System (IPEDS), available through the US National Science Foundation (NSF) via the National Center for Science and Engineering Statistics' reports and data tables and through an interactive WebCASPAR interface (https://ncsesdata.nsf.gov/webcaspar). Because all postsecondary institutions that grant federal financial aid are required to report to IPEDS, this coverage is nearly universal.

CRA's niche is in computing research, so our interest in students who could potentially choose research careers shaped our decisions about where to draw our study's boundaries. We chose, for example, to look only at bachelor's (BS), master's (MS), and doctoral (PhD) data. We didn't consider associate degrees or postsecondary certificates, although we recognize that two-year and other programs can provide an important pathway to baccalaureate study and certain careers in computing. At the BS level, we also consider the data from for-profit schools, but we focus primarily on public and private nonprofit institutions.

We studied data from 1990 to 2013. During this period, the computing field experienced significant growth and international attention from the Internet and dot-com boom, the subsequent bursting of the dot-com bubble, and the current era of new growth fueled by the ever-increasing business and social awareness of the power of the technology. It also witnessed the emergence of new areas within the computing field. The relationship between these major changes in the field and the participation of women was of particular interest.

Areas of Difference

Our investigation was interested in identifying differences in the representation of women along a variety of dimensions, including degree level, institutional characteristics, individual characteristics, and discipline within the computing field.

Level of Degree

Our work on the Taulbee Survey,[2] as well as others' work,[3,4] indicated substantial differences in the percentage of computing degrees granted to women at the graduate versus undergraduate levels. Hence, we wanted to make distinctions among the BS, MS, and PhD data. (In 2008–2009, IPEDS began to distinguish between PhD research and practitioner degrees. Almost all computing doctorates are research degrees, so our analysis aggregates all doctoral degrees.)

Institutional Characteristics

Two key types of institutional characteristics of interest to our study are those of private versus public and, at least for baccalaureate degree analyses, research versus nonresearch. Within the private category, those institutions that are for-profit are of interest as distinct from those that are nonprofit. Conventional wisdom is that research institutions provide more access to cutting-edge science, but nonresearch institutions, which tend to be smaller, provide a more supportive environment, which could be especially significant for members of underrepresented groups (http://chronicle.com/article/A-Hothouse-for-Female/21600).

The IPEDS database clearly disaggregates the data into public versus private, and private into for-profit and nonprofit. It further classifies institutions using Carnegie categories (http://carnegieclassifications.iu.edu) such as associates colleges, baccalaureate colleges, master's colleges and universities, doctoral/research universities, research universities (subdivided into high and very high research activity), special focus institutions, and tribal colleges. For our investigation, we defined research institutions as those classified under doctoral/research universities, research universities with high research activity, and research universities with very high research activity. All other institutions were classified as nonresearch.

Table 1. Classification of Instructional Programs (CIP) codes associated with each discipline.

Discipline	Code	Title
Computer science (CS)	11.0101	Computer and information sciences, general
	11.0102	Artificial intelligence
	11.0199	Computer science, other
	11.0701	Computer science
	11.9999	Computer and information sciences and support services
Computer engineering (CE)	14.0901	Computer engineering, general
	14.0902	Computer hardware engineering
	14.0999	Computer engineering, other
Software engineering (SE)	14.0903	Computer software engineering
Information systems (IS)	11.0501	Computer systems analysis/analyst
	52.1201	Management information systems, general
	52.1203	Business systems analysis and design
Information technology (IT)	11.0103	Information technology
	11.0201	Computer programming/programmer, general
	11.0202	Computer programming special applications
	11.0203	Computer programming, vendor/product certification
	11.0299	Computer programming, other
	11.0301	Data processing and data processing technology/technician
	11.0801	Webpage, digital/multimedia and information resources design
	11.0802	Data modeling/warehousing and database administration
	11.0804	Modeling, virtual environments and simulation
	11.0899	Computer software and media applications, other
	11.1001	Network and system administration/administrator
	11.1002	System, networking, and LAN/WAN management/manager
Information science (ISci)	11.0401	Information science/studies
Security (Sec)	11.1003	Computer and information systems security/information
Interdisciplinary (Idsc)	09.0702	Digital communication and media/multimedia
	10.0304	Animation, interactive technology, video graphics and special effects
	11.0104	Informatics
	11.0803	Computer graphics
	11.0901	Computer systems networking and telecommunications
	26.1103	Bioinformatics
	26.1104	Computational biology

	26.1199	Biomathematics, bioinformatics, and computational biology, other
	27.0303	Computational mathematics
	27.0304	Computational and applied mathematics
	30.0801	Mathematics and computer science
	30.1601	Accounting and computer science
	30.3001	Computational science
	30.3101	Human computer interaction
	50.0102	Digital arts
	51.2706	Medical informatics
Considered but not included	25.0101	Library and information science
	52.1206	Information resources management
	52.1207	Knowledge management
	52.1299	Management information systems and services, other

Table 2. Share of computing degrees by discipline in 2013.

	Bachelor's (BS) degrees		Master's (MS) degrees		Doctoral (PhD) degrees	
	Male and female	Female only	Male and female	Female only	Male and female	Female only
CS	33.1%	24.8%	38.4%	32.2%	62.1%	55.5%
CE	6.5%	3.2%	6.1%	4.1%	14.0%	10.4%
SE	0.8%	0.3%	3.5%	3.2%	0.2%	0.0%
IS	13.4%	17.5%	11.9%	12.9%	1.8%	2.0%
IT	19.4%	21.1%	12.7%	13.9%	3.1%	3.7%
Isci	8.2%	9.1%	13.2%	16.9%	6.0%	11.2%
Sec	5.7%	4.3%	4.9%	3.7%	0.7%	0.6%
Idsc	12.9%	19.7%	9.4%	13.2%	12.3%	16.5%
No. of degrees	71,289	13,978	31,098	8,731	2,490	490

Individual Characteristics

Along with institutional characteristics, we were interested in differences in participation patterns due to individual characteristics of the women, specifically those associated with their ethnicity and citizenship/residency status. What differences were present between majority and minority women? What differences in women's participation exist for nonresident women compared with resident majority or minority women?

The IPEDS database disaggregates its data by gender and by the ethnicity categories of "American Indian or Alaska native," "Asian or Pacific Islander," "Black, Non-Hispanic," "Hispanic," "White Non-Hispanic," "temporary resident," and "other/unknown races and ethnicities." For our analysis,

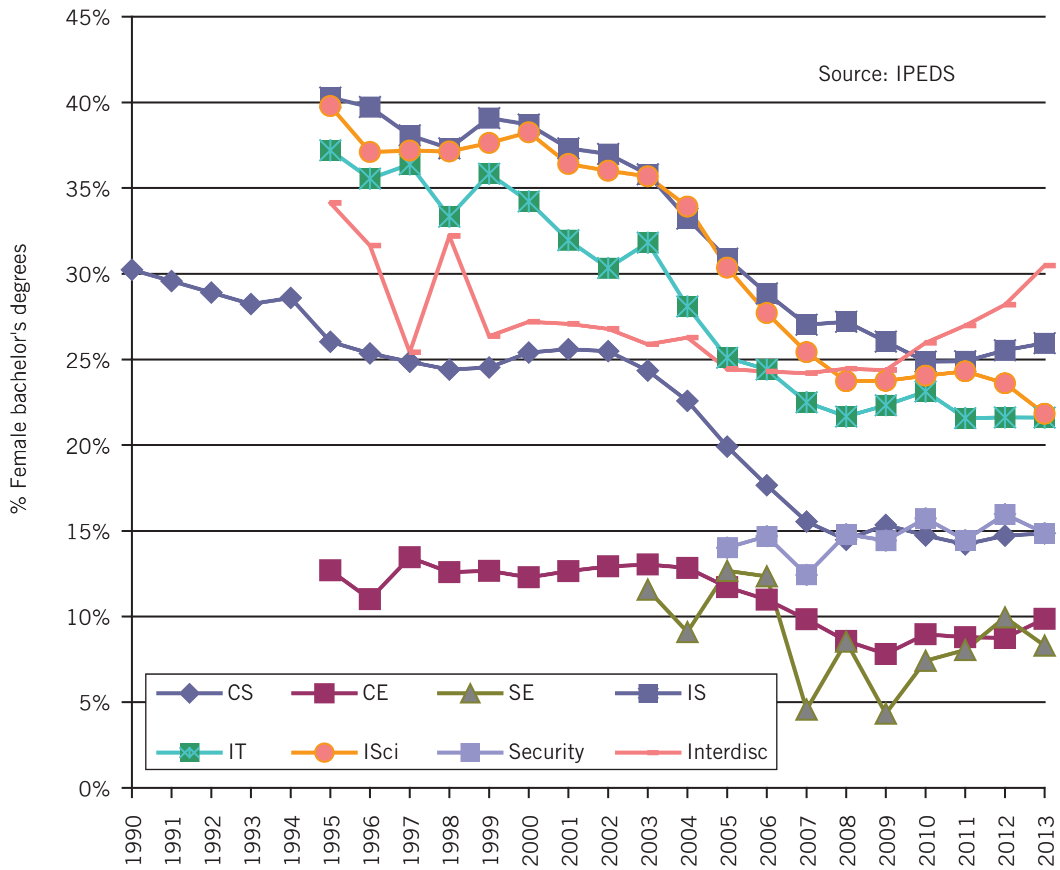

Figure 1. Percentages of female bachelor's degrees by discipline. The interdisciplinary area actually shows an increase in recent years, although the overall trend isn't significant.

we grouped these into three categories: majority, minority, and nonresident. We classified as minority those ethnicities traditionally underrepresented in computing, including "American Indian or Alaska native," "Black non-Hispanic," and "Hispanic." We classified "Asian or Pacific Islander" and "White non-Hispanic" as majority. The classification of "Asian and Pacific Islander" includes subgroups whose origin is from areas of Asia that clearly are well-represented in computing, as well as other subgroups whose origin isn't as well represented.[5] However, IPEDS doesn't collect data at a level of detail to permit this distinction, and Asian Americans as a broad group are well-represented in computing. We classified "temporary resident" as nonresident and omitted data from the category "other/unknown races and ethnicities" when analyzing individual characteristics.

Discipline

One of the key elements of our project was to determine the differences, if any, in the representation of women among the various major disciplines within the computing field. Many previous studies have either studied computer science alone or used the NSF detailed field designation of computer science ("academic discipline: detailed: computer science"), which aggregates data across several disciplines. Thus, one of our important tasks was to identify those data elements that should be associated with the different disciplines. The computing professional societies have defined five areas of interest and have issued curriculum recommendations for these areas: computer science (CS), computer engineering (CE), software engineering (SE), information systems (IS), and information technology (IT). Accreditation criteria have been defined for BS programs in each of these five areas.

Institutions report degree attainment data to IPEDS by the Classification of Instructional Programs (CIP) code. The CIP is a US Department of Education taxonomic scheme that supports the accurate

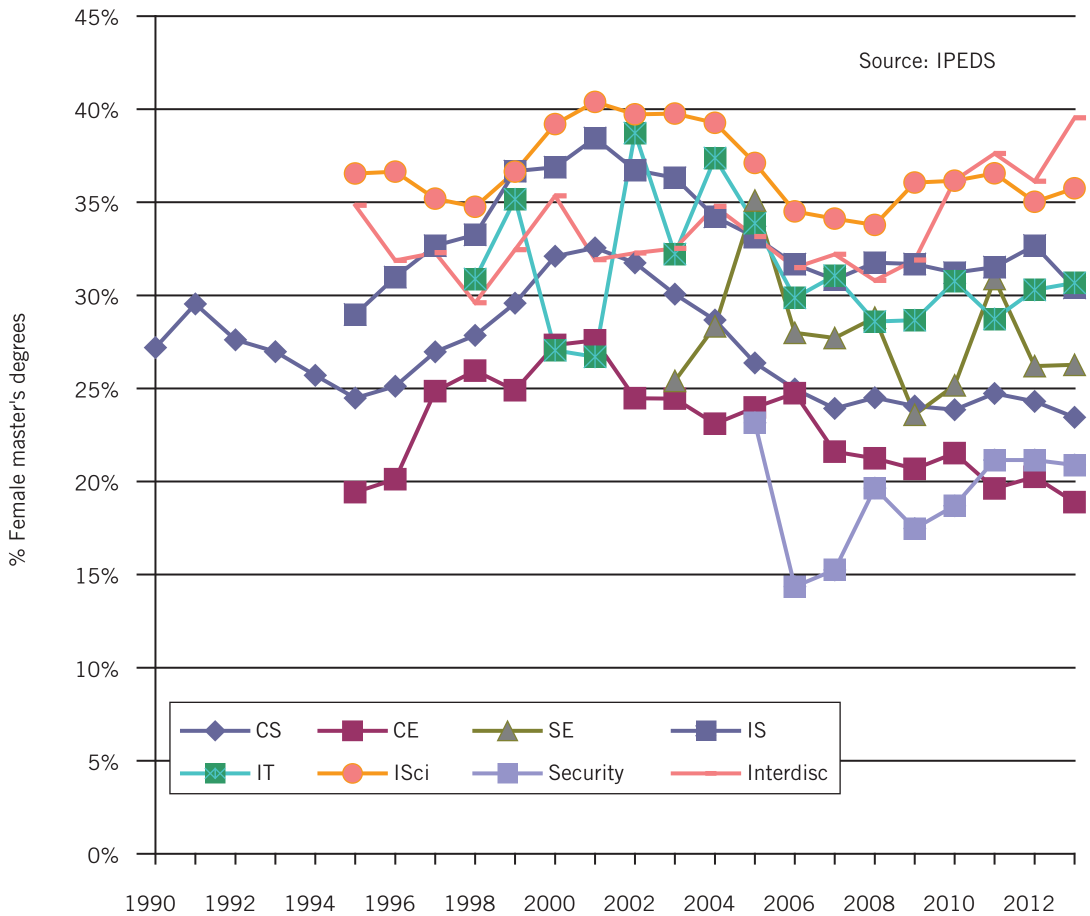

Figure 2. Percentages of female master's degrees by discipline. There's no significant trend for most of the disciplines, but there's a significant negative trend in computer science and a mildly significant negative trend in computer engineering.

tracking and reporting of fields of study and program completion across postsecondary programs (http://nces.ed.gov/ipeds/cipcode/Default.aspx?y=55). We found this to be the most precise way of selecting computing-related degrees and grouping them into disciplines. In general, multiple CIP codes are associated with any given computing area, but not all of them are within the broad area titled "computer and information sciences and support services." For example, there are relevant CIP codes in the areas of engineering, business, and multidisciplinary studies. The aggregation under the often-used detailed field designation "academic discipline: detailed: computer science" includes all CIP codes in the "computer and information sciences and support services" area (11.xxxx) except for 11.06 ("data entry"). However, not all of the 11.xxxx codes comprise what we typically mean by "computer science," although all of those (and more) fall within what we consider "computing."

We examined all the CIP codes in existence from 1990 to the present. There have been changes in these codes over time, with several new ones added and others deleted or merged. Each code has a description of its intended curricular focus. We used these and the names associated with each code to determine candidates for codes that fall within computing, including all codes in 11.xxxx as well as others outside of area 11.

We then looked more carefully at each of the selected codes to identify which computing discipline should be associated with the code. To assist us in this classification exercise, we frequently generated the set of institutions that identified graduates of programs with a particular code and examined a sample of these institutions' websites to learn more about the relevant program from that institution. From this information, we then classified the code into one of

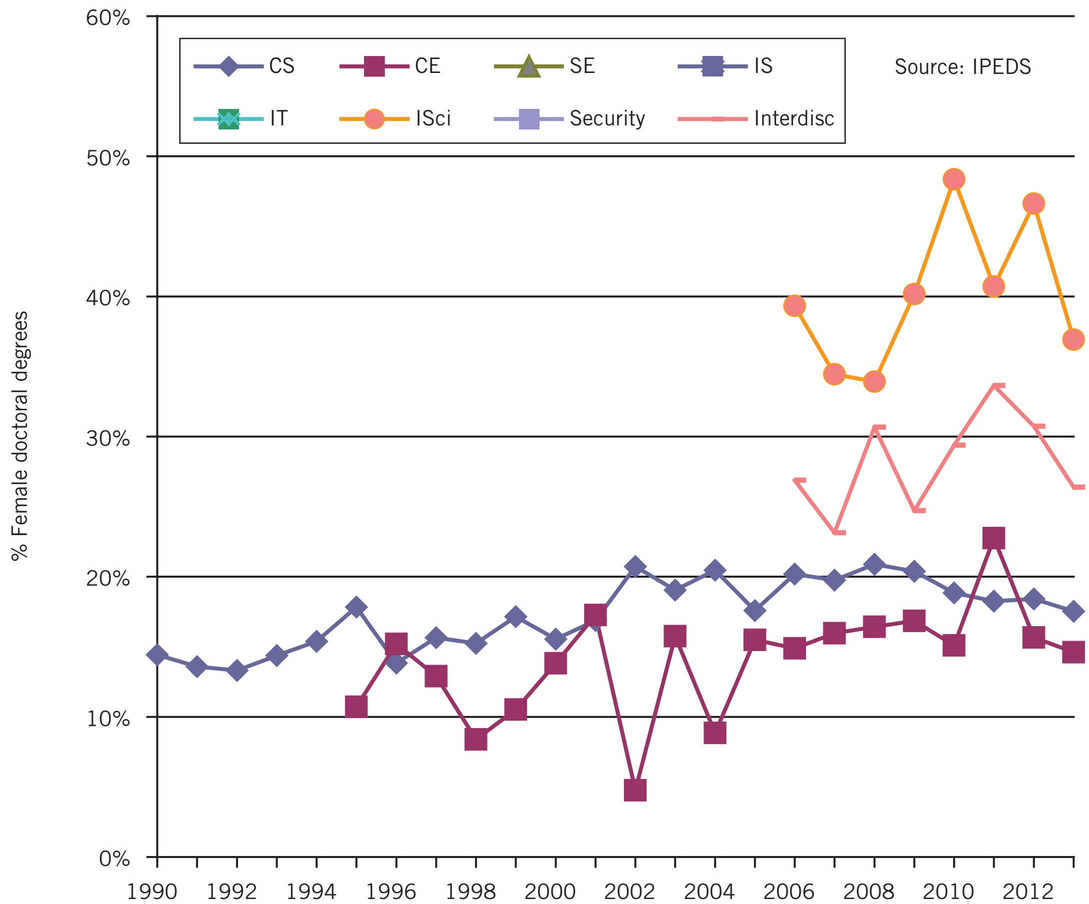

Figure 3. Percentages of female doctoral degrees by discipline. The percentages of female doctoral graduates for the CS, CE, and interdisciplinary areas tend to be in between the areas' respective percentages for BS and MS degrees.

Table 3. Overall trends for females by discipline and degree level since 1990.*

Degree	CS	CE	SE	IS	IT	ISci	Sec	Idsc
BS	↓***	↓***	↔	↓***	↓***	↓***	↑°	↔
MS	↓**	↓°	↔	↔	↔	↔	↔	↔
PhD	↑***	↑*	N/A	N/A	N/A	↔	N/A	↔

* Key:
↑ increasing trend
↓ decreasing trend
↔ no significant trend
N/A insufficient data for analysis

° significance level = .10
* significance level = .05
** significance level = .02
*** significance level = .01

several computing areas. Initially, we classified the code into the six areas: computer science (CS), computer engineering (CE), software engineering (SE), information systems (IS), information technology (IT), or none of these. We used our understanding of these areas as described in the ACM curricula report[6] as the basis for this determination. In some cases, we determined that the

Table 4. Total BS degrees in 2013 by institution type and discipline.						
	Private for-profit	Private nonprofit		Public		Total
		Research	Nonresearch	Research	Nonresearch	
CS	540	2,968	4,698	9,588	6,487	24,281
CE	17	488	420	3,230	578	4,733
SE	179	29	145	132	105	590
IS	1,536	561	1,817	3,964	1,969	9,847
IT	6,967	808	2,155	2,194	2,078	14,202
ISci	748	410	465	2,056	2,362	6,041
Sec	3,050	143	462	68	473	4,196
Idsc	3,321	467	2,285	2,460	891	9,424
Total	16,358	5,874	12,447	23,692	14,943	73,314

programs reporting a particular CIP code didn't really appear to be computing programs at all but instead were programs in another discipline with little if any computing requirement, or were codes that were used for certificate programs but not for baccalaureate or postbaccalaureate programs. In these cases, we eliminated the code as a candidate for further analysis. For those codes that weren't eliminated but that weren't categorized into the five areas, we identified three other areas for separate analysis: information science (ISci), security (Sec), and interdisciplinary (Idsc). ISci was singled out from IT and IS at the recommendation of colleagues from the dean's group of the CRA. Security was singled out as an area in which there currently is some active effort to identify possible program criteria for accreditation.

Table 1 summarizes the CIP codes that we concluded should be associated with each discipline.

Because new codes were introduced over time, some of the ones that were valid both before and after a new code was introduced could aggregate data from multiple disciplines prior to the new disciplinary codes being introduced. We note this as a source of error for which we can't correct, given the level of data specificity. For example, prior to 1995, when a separate ISci code was introduced, the code 11.9999 likely included degree production in what we refer to as ISci in addition to degree production in CS. The more recent data likely has less confounding in this respect than does the data from earlier years.

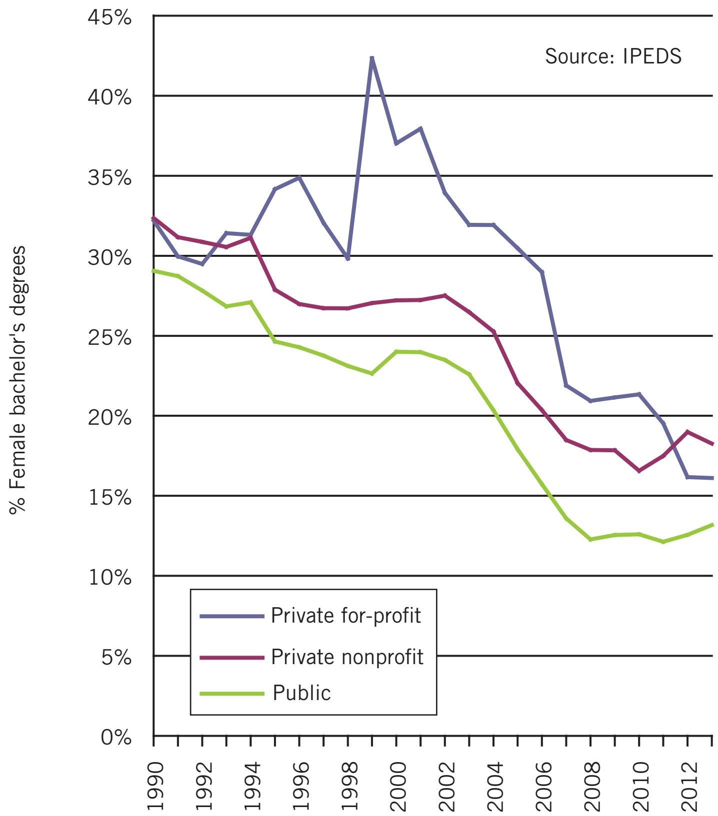

Figure 4. Percentages of female bachelor's degrees by institutional control, CS only. For most years, the percentage of women at private for-profit institutions is greater than the percentage of women at private nonprofit institutions.

Results

We're primarily interested in trends in the participation of women over the period of 1990–2013.

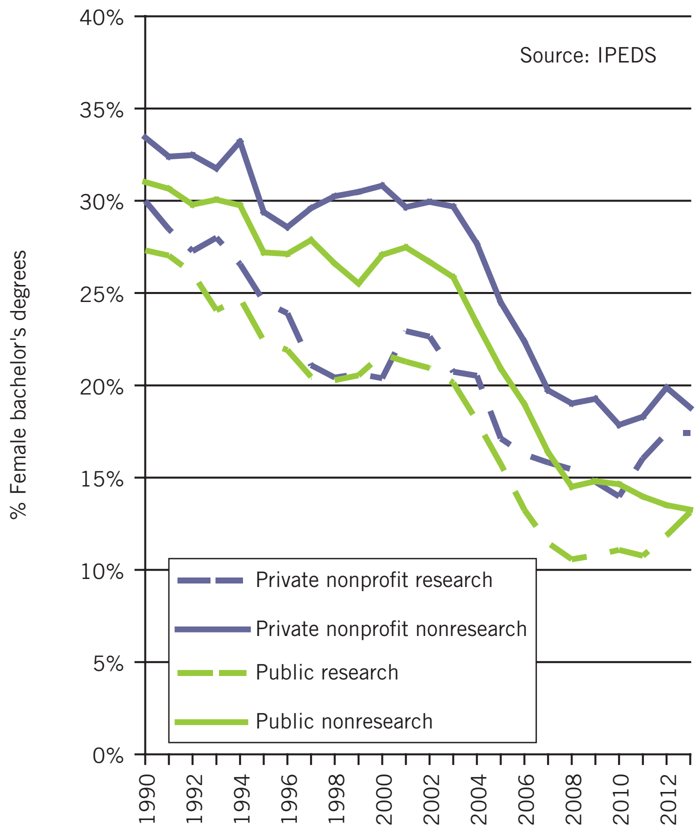

Figure 5. Percentages of female bachelor's degrees by institution type, CS only. Nonresearch institutions granted a higher percentage of BS degrees to women than did research institutions.

However, to put these trends in context, we must also consider the distribution of degrees across the disciplines, a number that differs by degree level and over time. Depending on the degree level, institutional characteristics, individual characteristics, or disciplines under study, there can be insufficient data for a trend analysis to be meaningful. Thus, our presentation will include data only from those years in which a sufficient number of degrees were produced to allow meaningful trend analysis.

Table 2 illustrates the proportion of computing degrees produced by each discipline during the most recent year (2013). It also shows the discipline's proportion of computing degrees granted to women in that year: CS accounts for about one-third of all computing BS degrees, but only about one-quarter of computing BS degrees granted to women.

We tested the significance of trends over time using the Spearman rank correlation coefficient, with year and percent of women participation as the two variables whose ranks are compared. Significant positive (increasing) trends are indicated by a significant positive correlation, and significant negative (decreasing) trends are indicated by a significant negative correlation.

A second type of analysis involves comparing two participation variables—for example, we're interested in comparing the degrees granted to women at public versus private institutions. For such comparisons, we used the Wilcoxon Matched-Pairs Signed-Ranks Test. Each year's data about percent of women for the two variables being compared is a matched-pair for the purposes of these tests.

We used nonparametric tests for each type of analysis to compensate for the uncertainty that the assumptions of parametric tests (such as ANOVA) were met. All tests are two-tailed, and possible alpha levels are .01, .02, .05, and .10. For these analyses, the two-tailed test is very conservative: a two-tailed test significant at alpha = .10 (.02) would be significant at alpha = .05 (.01) for a one-tailed test.

Overall Trends by Degree Level

We discuss in turn the respective trend analysis at the BS, MS, and PhD levels.

BS degrees. Figure 1 shows the overall trend of the percentage of BS degrees awarded to women in each discipline. Most disciplines show a negative trend. However, the interdisciplinary and SE areas show no significant trend. The SE area has data for fewer years than most. The interdisciplinary area actually shows an increase in recent years, although the overall trend isn't significant. The security area shows a mildly significant increasing trend (alpha = .10) and is the other area for which sufficient data has only been available for a relatively short time. The other five areas (CS, CE, IS, IT, and ISci) all show negative trends significant at alpha = .01 with no evidence of recent increases.

Figure 1 also illustrates that the timing of the declines in percentages of BS degrees to women varies somewhat from one discipline to another. The information disciplines (IS, IT, and ISci) began declines right around the start of the millennium but deepened toward the mid-2000s. CS declines began around 2003, and CE declines began around 2005. The various declines tended to last until the late 2000s no matter when they began. The representation of women among graduates in each of these disciplines appeared to be adversely affected by the changing employment climate in computing brought on when the dot-com bubble burst at the start of the millennium.

Table 5. Comparisons by institutional characteristics.*

Comparison	CS	CE	SE	IS	IT	ISci	Sec	Idsc
BS								
Private nonprofit: private for-profit	<***	N/A	N/A	↔	>*	↔	N/A	>***
Private nonprofit: public	>***	>**	N/A	>***	>***	>***	N/A	>**
Private nonprofit, nonresearch: research	>***	↔	N/A	↔	↔	>***	N/A	↔
Public nonresearch: research	>***	>***	N/A	>*	>°	↔	N/A	<*
MS								
Private nonprofit: public	↔	↔	<***	↔	>***	<***	N/A	<°
PhD								
Private nonprofit: public	>***	N/A	N/A	N/A	N/A	N/A	N/A	N/A

* Key for A:B comparisons

>	A > B	°	significance level = .10
<	A < B	*	significance level = .05
↔	no significant difference	**	significance level = .02
		***	significance level = .01

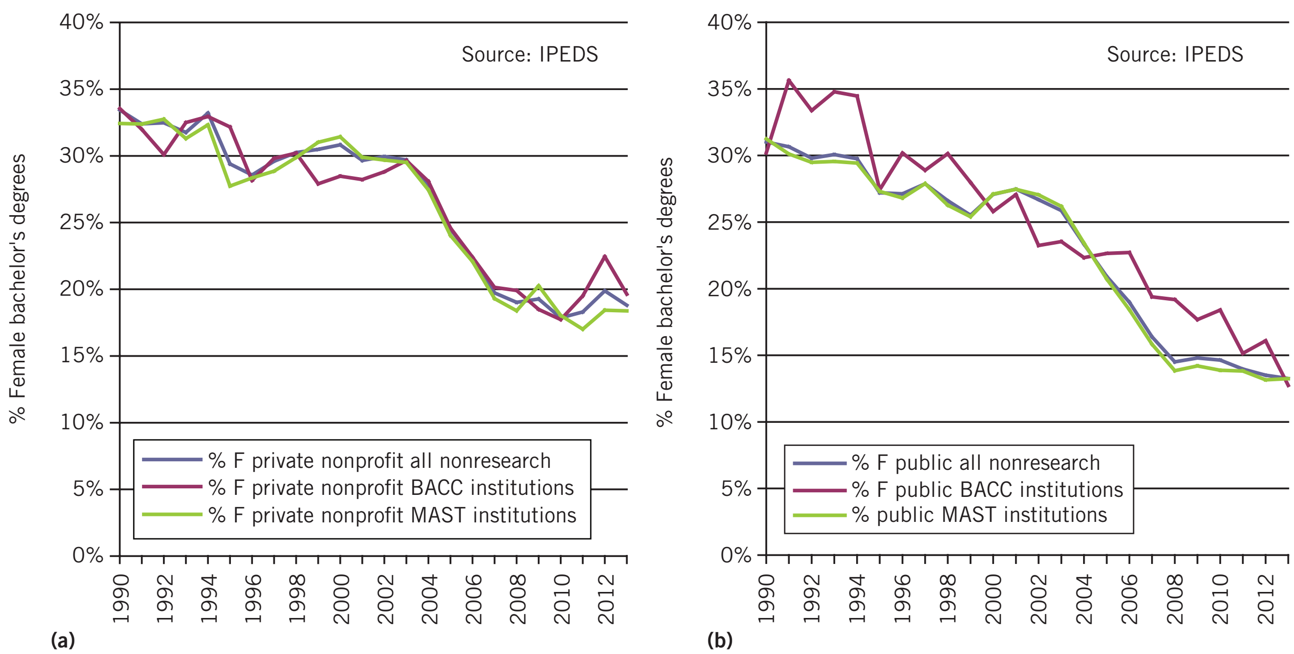

Figure 6. Percentages of female computer science bachelor's degrees at (a) private nonprofit and (b) public baccalaureate colleges versus master's colleges and universities. Individual trends for BACC and MAST institutions are very similar to each other and to those for all nonresearch institutions combined.

The different disciplines consistently have very different percentages of female graduates, with the highest percentage in interdisciplinary (just over 30 percent in 2013) followed by IS (about 26 percent in 2013). CE and SE have the smallest percentages of female graduates, at or below 10 percent in recent years.

MS degrees. Figure 2 shows trends by discipline for the percentage of MS degrees awarded to women.

Table 6. BS degree trends for women at baccalaureate colleges and master's colleges and universities.*

Analysis	CS	IS	IT	Idsc
Private nonprofit				
All nonresearch institutions	↓***	↓***	↓***	↓***
BACC institutions	↓***	↓***	↓***	↓***
MAST institutions	↓***	↓***	↓***	↓**
Public				
All non-research institutions	↓***	↓***	↓***	↓*
BACC institutions	↓***	↓***	↓°	↔
MAST institutions	↓***	↓***	↓***	↔

* IT nonprofit begins 1997; IT public BACC begins 2004; Idsc private nonprofit begins 1999; Idsc public BACC begins 2004; Idsc public MAST begins 2002; all other IS, IT, Idsc begin 1995; CS begins 1990.

* Key:
↑ increasing trend
↓ decreasing trend
↔ no significant trend
N/A insufficient data for analysis
° significance level = .10
* significance level = .05
** significance level = .02
*** significance level = .01

Table 7. Total bachelor's degrees in 2013 by individual characteristic.

	Nonresident	Majority	Minority	Total
CS	1,700	17,108	3,748	22,556
CE	381	3,341	757	4,479
SE	32	437	93	562
IS	494	6,253	2,506	9,253
IT	364	8,707	2,956	12,027
ISci	314	3,881	1,432	5,627
Sec	34	2,438	1,183	3,655
Idsc	315	5,936	2,111	8,362
Total	3,634	48,101	14,786	66,521

There's no significant trend for most of the disciplines, but there's a significant negative trend in CS (alpha = .02) and a mildly significant negative trend in CE (alpha = .10). As with the BS degrees, the percentage of degrees awarded to women varies from one discipline to another, with IS and interdisciplinary being the highest. Note that in many of the disciplines, there were increases in the percentage of women receiving degrees from the mid-1990s through the early 2000s, followed by declines for each discipline (of varying lengths). For most disciplines, the percentages have leveled off in recent years, although the interdisciplinary area has grown. Comparing Figures 1 and 2, we also see that for each discipline, the recent percentage of MS degrees awarded to women is higher than the percentage of BS degrees awarded to women, even after we account for a multiyear lag in the typical timing of receipt of an MS degree relative to the year in which the BS degree was obtained.

PhD degrees. Sufficient data to analyze PhD degree production trends is only available for the CS, CE, ISci, and interdisciplinary areas (Figure 3). The CS and CE trends are positive. CS's positive trend is significant at alpha = .01, and computer engineering's is at alpha = .05. The ISci and interdisciplinary trends aren't significant. The percentages of female doctoral graduates for the CS, CE, and interdisciplinary areas tend to be in between the areas' respective percentages for BS and MS degrees. The ISci area's percentage of female doctoral graduates exceeds those from that discipline for BS or MS degrees.

Summary of overall degree trend results. Table 3 summarizes the results of our analysis of trends by degree level and discipline. In general, since 1990, the percentage of PhD degrees in computing that were received by women has increased, but the percent of BS and MS degrees received by women has decreased or held steady.

Trends by Institutional Characteristics

We performed similar trend analyses for each discipline, disaggregating the data by institutional characteristic. We were interested in comparing public institutions with private nonprofit institutions at all degree levels. At the BS level, we were also interested in comparisons of private for-profit with private nonprofit, and research with nonresearch institutions.

Table 4 shows the total number of BS degrees granted in 2013 to men and women combined, for each discipline and type of institution. Private for-profits granted 22 percent of computing degrees overall but only 2 percent in CS. Among private nonprofits, nonresearch institutions granted more degrees than did research institutions except in CE. Among public institutions, research institutions granted more degrees than did nonresearch institutions except in ISci and Sec.

Public/private and research/nonresearch analyses. Figures 4 and 5 depict the trends at the BS level for CS only. Figure 4 illustrates the trends for the percentages of CS BS degrees that were granted to women at private for-profit, private nonprofit, and public institutions without regard for research or nonresearch status. Figure 5 illustrates the trends for research and nonresearch institutions by public and private nonprofit institutions.

Figure 4 shows that the percentage of CS graduates who are women at private nonprofit institutions is greater than the percentage who are women at public institutions, and that, for most years, the percentage at private for-profit institutions who are women is greater than the percentage of women at private nonprofit institutions. The differences across institutional control are significant at the alpha = .01 level. Furthermore, the overall trend for each institution type is decreasing, significant at alpha=.01.

Figure 5 shows that the decreasing trend for both public and private nonprofit institutions is present even when each of these institution types is disaggregated into research and nonresearch institutions (at alpha = .01 in each case). Figure 5 also shows that nonresearch institutions granted a higher percentage of BS degrees to women than did research institutions. This is true at alpha = .01, whether the institutions being compared were public or private not-for-profit.

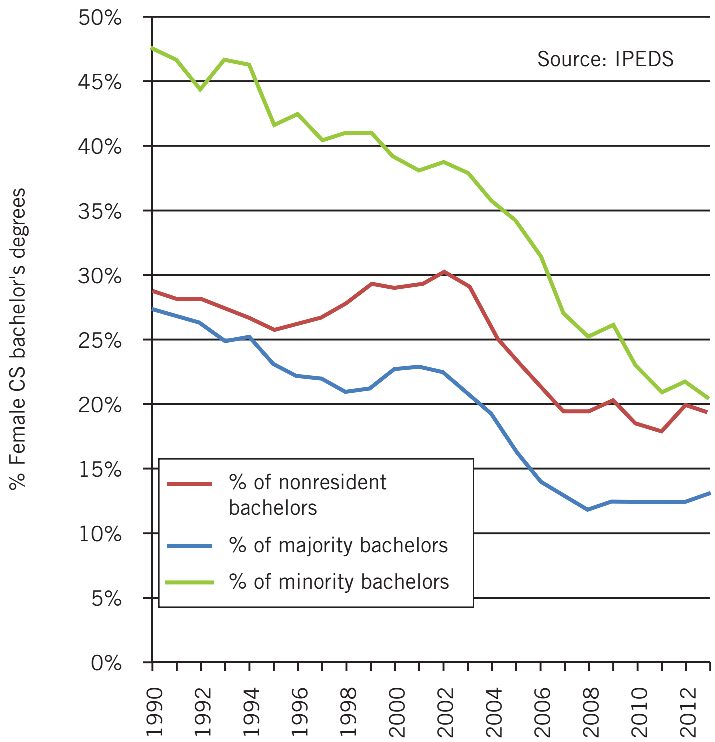

Figure 7. Percentages of female bachelor's degrees by ethnicity, CS only. In all years, minority graduates are more likely to be female than are nonresidents, who in turn are more likely to be female than are majority graduates.

Looking more carefully at the last few years' trends exhibited in Figure 5, we see an increasing trend in the proportion of female BS graduates at research institutions, both public and private nonprofit. Among nonresearch institutions, there's no clear trend at private nonprofit institutions, and there continues to be a decreasing trend at public institutions. The increasing trends at research institutions bears watching, as the recent surge in CS enrollments manifests itself in increased overall degree production. There are serious pressures being felt by academic departments in coping with this enrollment surge, and the manner in which departments cope with the surge can affect diversity.

We performed analyses of the long-term trends based on institutional characteristics for all disciplines. Table 5 summarizes the results.

At the BS level, all disciplines in which a comparison between public and private nonprofit was possible showed higher percentages of women at private nonprofit institutions. MS results were mixed across the different disciplines.

Among private nonprofit institutions, only the ISci area showed the same results as CS relative

Table 8. Comparisons by individual characteristics.*

Analysis	CS	CE	SE	IS	IT	ISci	Sec	Idsc
BS								
Majority	↓***	↓***	↓°	↓***	↓***	↓***	↔	↔
Minority	↓***	↓***	N/A	↓***	↓***	↓***	↔	↓***
Nonresident	↓***	↔	N/A	↓***	↓*	↓***	N/A	↔
Minority: majority	>***	>***	N/A	>***	>***	>***	>***	>***
Nonresident: majority	>***	>***	N/A	>***	>***	>***	N/A	>***
MS								
Majority	↓***	↓***	↔	↓***	↔	↓°	↔	↔
Minority	↓***	↓°	N/A	↓°	↓**	↓***	N/A	↑*
Nonresident	↑*	↔	↔	↔	↔	↔	N/A	↔
Minority: majority	>***	>°	N/A	>***	>***	>***	N/A	>***
Nonresident: majority	>***	>***	↔	>***	>***	↔	N/A	>*
PhD								
Majority	↔	↔	N/A	N/A	N/A	N/A	N/A	N/A
Minority	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Nonresident	↑***	↑***	N/A	N/A	N/A	N/A	N/A	N/A
Nonresident: majority	>**	N/A	N/A	N/A	N/A	N/A	N/A	N/A

* Key for A:B comparisons

>	A > B	°	significance level = .10
<	A < B	*	significance level = .05
↔	no significant difference	**	significance level = .02
		***	significance level = .01

to research and nonresearch institutions; the other four areas where comparisons were possible showed no significant difference between research and nonresearch institutions. Among public institutions, CE, IS, and IT showed nonresearch institutions having higher percentages of women, with varying degrees of significance, whereas ISci showed no significant difference; for the interdisciplinary area, women were better represented at research institutions.

Further analysis of nonresearch institutions. The majority of institutions within our nonresearch classification are those within Carnegie categories "baccalaureate colleges" (BACC) and "master's colleges and universities" (MAST). Baccalaureate Colleges award fewer than 50 MS degrees institution-wide. We were interested in seeing if the representation of women differed in nonresearch institutions whose classification suggested that they had little graduate program activity from those whose classification suggested more prominence of their graduate programs.

We examined the differences between these two categories of institutions for the four computing disciplines producing the highest number of degrees (CS, IS, IT, and Idsc). Figures 6a and 6b show the trends within CS at private nonprofit and public institutions, respectively. Clearly, the individual trends for BACC and MAST institutions are very similar to each other and to those for all nonresearch institutions combined. Table 6 summarizes the comparisons for each of the four disciplines, highlighting that there's little difference in the BACC and MAST trends within any of the disciplines, with the

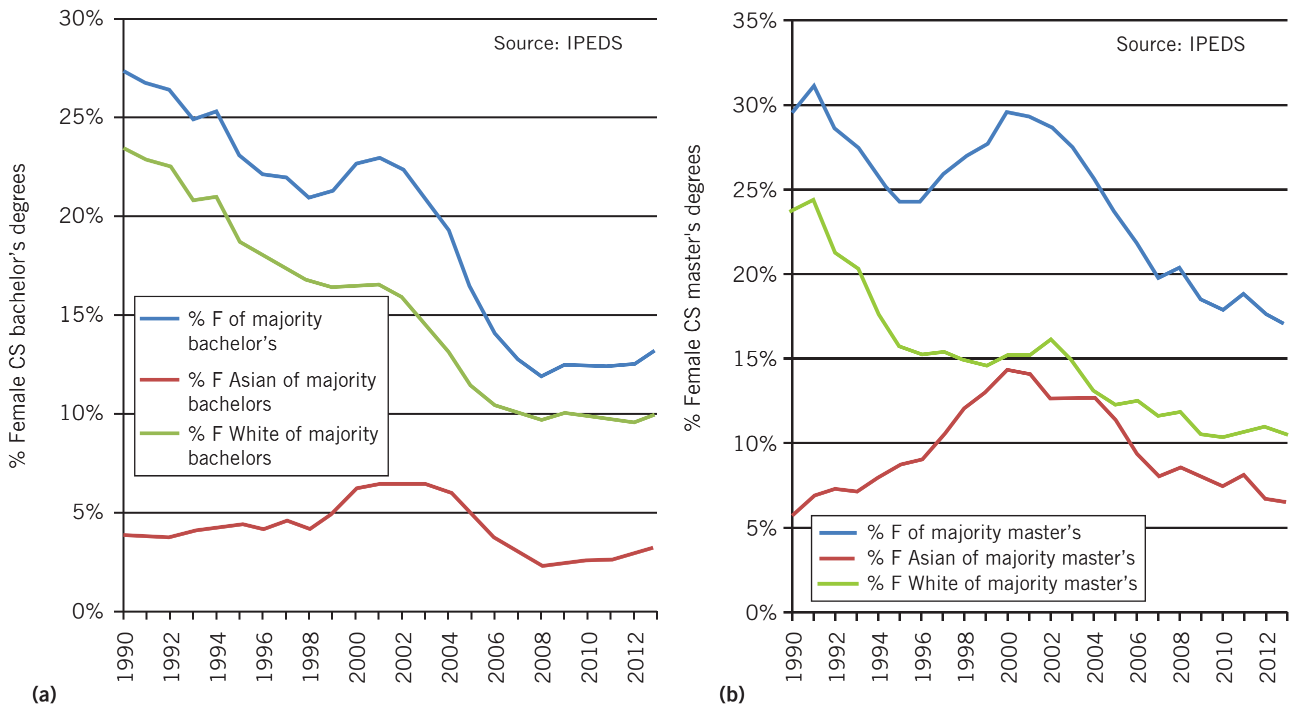

Figure 8. Asian versus White women among majority CS (a) BS and (b) MS degrees. As expected, for White women, the trends mirror those for majorities as a whole; the Asian BS trend is negative but significant only at alpha = .10.

exception of Idsc public institutions, where the overall nonresearch trend is significant at alpha = .05, but the BACC and MAST trends aren't significant. This is due to differences in the period during which there's sufficient data to analyze different cells' trends. If the overall Idsc trend is analyzed during the period of 2002–2013 instead of 1995–2013, the trend isn't significant, which is consistent with the BACC and MAST findings.

Trends by Individual Characteristic

To analyze differences based on individual characteristics, for each disciplinary area we disaggregated the IPEDS degree production data according to whether the individual obtaining the degree was a majority, minority, or nonresident, as defined earlier. Table 7 shows the total number of BS degrees granted to men and women combined in 2013, for each discipline by individual characteristic.

Figure 7 illustrates the differences in trends among these three categories for CS BS degrees. The figure shows declining percentages of women for each category and also shows that in all years, minority graduates are more likely to be female than are nonresidents, who in turn are more likely to be female than are majority graduates. Statistical analyses of each of these trends is significant at alpha = .01.

We performed similar analyses of individual characteristics for each discipline. Table 8 shows the summary of the analyses. It includes both the trend for each discipline and ethnicity group and the comparisons between ethnic groups.

Where there are significant BS trends in a given ethnicity category, they're always negative, that is, showing a declining percentage of women over time. At the MS level, several trends were negative, but only among majorities and minorities (not among nonresidents); the interdisciplinary area had a positive trend for minorities. Nonresident MS trends were almost always not significant, although there was a positive trend in CS.

In every discipline in which a comparison between minorities and majorities could be made, it was more likely that a minority BS recipient would be female than that a majority recipient would be female. The same is true for MS degree recipients. In most disciplines in which a comparison could be made, whether at the BS or MS level, it was more likely that a nonresident degree recipient would be female than that a majority degree recipient would be female.

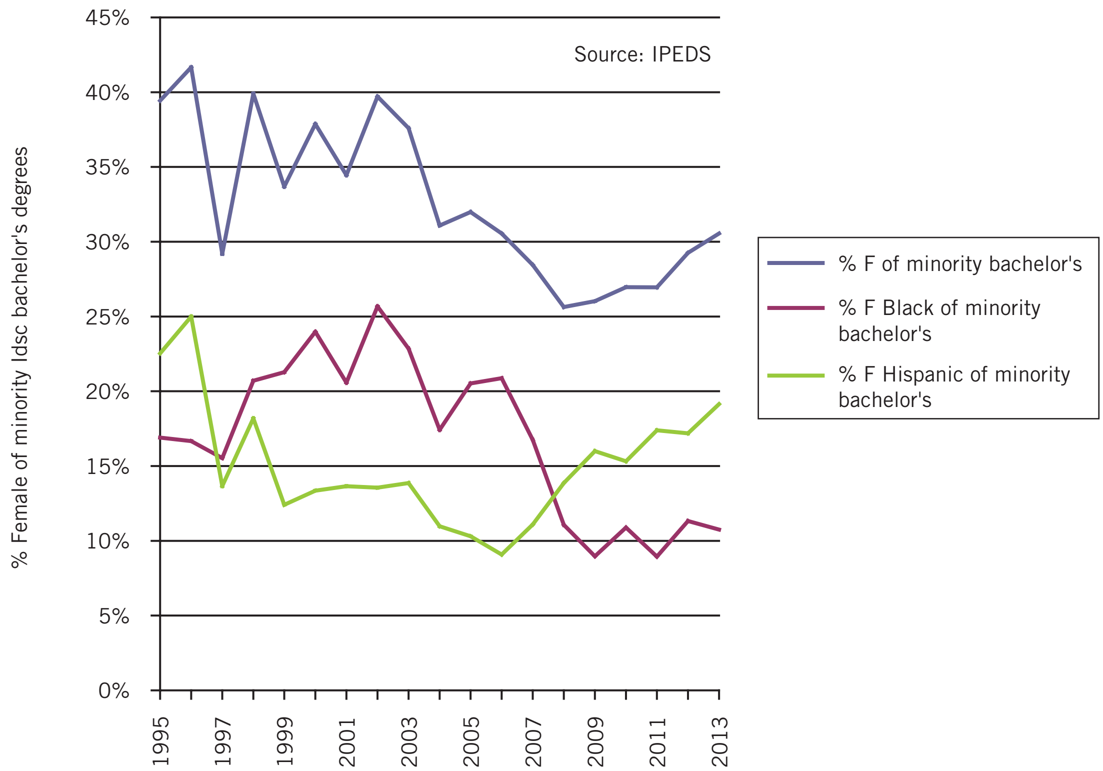

Figure 9. Black versus Hispanic women among minority interdisciplinary BS degrees. Of interest is the rise in Hispanic women's percentage of all minority BS degrees since 2006, while the percentage of Black women among minority BS degrees declined sharply during the late 2000s and has remained at this lower level.

Further analysis of majorities. Our majorities category consists of Whites and resident Asians. While Whites comprise the preponderance of this category (of the 17,108 majority graduates in 2013 shown in Table 6, only 2,786 are Asian) and therefore are highly likely to exhibit the trend for overall majorities, we were interested to see if the trend for Asian women was similar. We again investigated the four largest disciplines (CS, IS, IT, and Idsc) separately. We disaggregated both the BS and MS majority data.

Figures 8a and 8b illustrate the results of the disaggregation for CS.

As expected, for White women, the trends mirror those for majorities as a whole; they're significantly negative at alpha = .01. However, the Asian bachelor's trend is negative but significant only at alpha = .10. There was no significant change in the percentage of Asian women among majority MS degree holders. Note the increase in the percentage of majority MS degrees going to Asian women from the mid-1990s through the early 2000s, followed by a decline since 2005. The percentage of majority MS degrees to White women, by contrast, has had no real growth period since 1990.

Table 9 summarizes the analyses for each of the four disciplines. Note that in each case, the trends for White women mirror those for all majorities, while in most cases, the trend for Asian women is more favorable. The trends for Asians weren't significant for IT BS, CS MS, or IS MS degrees when those overall majority trends were significantly negative at alpha = .01. In the interdisciplinary area, the percentage of majority MS degrees to Asian women increased significantly at alpha = .01, while there was no significant change in the percentage of majority MS degrees to women overall.

Further analysis of minorities. The vast majority of people in the minorities category are Blacks or Hispanics. We were interested to see if there are differences in the trends for these two individual categories of minority female graduates within the four disciplines of CS, IS, IT, and interdisciplinary. We did this analysis only at the BS level, where there is sufficient data across all years for all four disciplines.

Table 10 shows the results. With the exception of the interdisciplinary area, there were no differences between Black and Hispanic trends, nor any

Table 9. Trends for Asian versus White women among majority degree holders.

Analysis	CS	IS	IT	Idsc
BS				
All majorities	↓***	↓***	↓***	↔
Asian	↓°	↓**	↔	↔
White	↓***	↓***	↓***	↔
MS				
All majorities	↓***	↓***	↔	↔
Asian	↔	↔	↔	↑***
White	↓***	↓***	↔	↔

* Key: ↑ increasing trend; ↓ decreasing trend; ↔ no significant trend; N/A insufficient data for analysis; ° significance level = .10; * significance level = .05; ** significance level = .02; *** significance level = .01

difference from the overall minority trend. However, the interdisciplinary area showed a difference in both Black and Hispanic trends from the overall minority trend. The overall minority trend was negative, significant at alpha = .01. While the Black trend still was negative, its significance level was only .02. The Hispanic trend wasn't significant. Figure 9 shows the trend lines that gave rise to this unusual set of significance tests in the interdisciplinary area. Of interest is the rise in Hispanic women's percentage of all minority BS degrees since 2006, while the percentage of Black women among minority BS degrees declined sharply during the late 2000s and has remained at this lower level.

Table 10. Trends for Black versus Hispanic women among minority BS degree holders.

Analysis	CS	IS	IT	Idsc
All minorities	↓***	↓***	↓***	↓***
Black	↓***	↓***	↓***	↓**
Hispanic	↓***	↓***	↓***	↔

The differences identified through these analyses have several important implications for researchers, institutions and mentoring programs interested in increasing the participation of women in computing. They can help identify more targeted future studies to explore the reasons behind the differences. They can also suggest subgroups that might benefit from different types or levels of support. And they suggest that intervention programs that benchmark progress against national-level data should pay close attention to matching their program population with comparable national data for the most accurate results. ■

Acknowledgments

This work was supported by grant B2014-12 from the Alfred P. Sloan Foundation. A portion of this article was presented at the RESPECT Conference on 14 August 2015. We thank Wendy DuBow and Ellen Walker for their comments on a draft version, and also thank the RESPECT Conference reviewers for their insights and suggestions. The feedback improved the manuscript.

References

1. J. Prey et al., "ACM NDC Study: Second Annual Study of Non-Doctoral-Granting Departments in Computing," *ACM Inroads*, Sep. 2014, pp. 14–26.
2. S. Zweben and B. Bizot, "CRA Taulbee Survey Report 2014: Relentless Growth in Undergraduate CS Enrollment; Doctoral Degree Production Remains Strong but No New Record," *Computing Research News*, May 2015; http://cra.org/resources/crn-archive-view/2015/05.
3. T. Camp, "Computing, We Have a Problem...," *ACM Inroads*, Dec. 2012, pp. 34–40.
4. I. Becerra-Fernandez, J. Elam, and S. Clemmons, "Reversing the Landslide in Computer-Related Degree Programs," *Comm. ACM*, Feb. 2010, pp. 127–133.

5. R. Teranishi, L. Lok, and B.M.D. Nguyen, *iCount: A Data Quality Movement for Asian Americans and Pacific Islanders in Higher Education*, 2013; care.gseis.ucla.edu/wp-content/uploads/2015/08//2013_iCount_Report.pdf.
6. R. Shackelford et al., *Computing Curricula 2005*, 2005; www.acm.org/education/education/curric_vols/CC2005-March06Final.pdf.

Stuart H. Zweben is professor emeritus of computer science and engineering at the Ohio State University. His research interests include software engineering and computer science education. Zweben received a PhD in computer science from Purdue University. He's a fellow and former president of ACM, a fellow and former president of the Computing Sciences Accreditation Board (CSAB), and a Fellow of ABET. Contact him at zweben.1@osu.edu.

Elizabeth B. Bizot is the Director of Statistics and Evaluation at the Computing Research Association. Her research interests include underrepresented groups in science and engineering, career and graduate education choices in computing research, and higher education data in computing. Bizot received a PhD in industrial/organizational psychology from the University of Tulsa. She's a member of the American Evaluation Association, the ACM, and the IEEE special technical community on broadening participation. Contact her at bizot@cra.org.

cn *Selected articles and columns from IEEE Computer Society publications are also available for free at http://ComputingNow.computer.org.*