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REPORT

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Number of Women in Physics Departments: A Simulation Analysis

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Women's representation in physics lags behind most other STEM disciplines. Currently, women make up about 13% of faculty members in all physics degree–granting departments, and there are physics departments with no women faculty members at all. These two data points are often cited as evidence of a lack of equity for women.

The number of departments with no women among their faculty members seems appealing as a measure of equity by sex. At first glance, it may seem that as the representation of women in physics increases, all departments "should" have at least one woman faculty member. However, we will show that this is an unlikely outcome. In fact, if we took all of the women in bachelor's-granting departments and assigned each one to a different department, almost one-third of the departments would still have no women among their faculty members.

In this article, we demonstrate that two factors affect the representation of women in a single physics department:

- the number of faculty members in the single department and
- the overall proportion of women among all current physics faculty.

There are a number of physics departments with only two or three faculty members; it is unlikely that these departments will have a woman among the faculty because the overall representation of women among all physics faculty members is low. We will examine this point more closely using the binomial distribution which includes two parameters: *n* and *p*. In this analysis, the number of faculty members in a single physics department is *n*, and the overall proportion of women among all current physics faculty members is *p*. Our results suggest that that we should not accept the absence of women in a particular department as evidence that the department is biased against women.

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We begin by presenting the current situation of women's representation in physics departments. Next, we present the results of simulations that

calculate the expected number of departments that have no women faculty members. These simulations are based on actual data about the profile of degree-granting physics departments and the representation of women in physics. Using these data and applying the binomial distribution, we calculate the expected proportions of departments with no women.

Finally, we compare these expected proportions to the actual proportions of departments with no women. We are able to show that the actual proportion of departments with no women is lower than expected for PhD-granting departments. For bachelor's-granting departments, the actual proportion of departments with no women is about the same as the expected proportion.

We also include an analysis using hypothetical values for the proportion of women among the physics faculty to examine what might happen as the representation of women increases.

The Current Situation

Women make up 13% of professorial-rank faculty members (assistant, associate, and full professors) overall. However, the proportion of women is different in PhD-granting physics departments than it is in bachelor's-granting physics departments. While women's representation is higher in bachelor's-granting departments (16% versus 11%), the bachelor's departments average fewer faculty members than departments which grant doctorates (**Table 1**).

Women's representation in physics has been slowly increasing. Yet there remain many departments that have no women on the faculty. In fact, almost half of bachelor's departments and 8% of PhD departments have faculties that are all the same sex. (Most of these single-sex departments have no women; there are a few with no men.) This paper will explain that much of the reason for this has to do with the number of physics faculty members in each department and the representation of women among physics faculty members overall.

Table 1

Basic Data on Faculty Members in Degree-Granting Physics Departments

Highest Physics Degree Awarded	Bachelor's	PhD
Smallest Department (# of faculty members)	1	3
Median Size (# of faculty members)	4	22
Largest Department (# of faculty members)	27	75
Women's Representation among Professorial-Rank Faculty Members	16%	11%
Departments That Have No Women	47%	8%
Departments That have No Men	1%	0%
Number of Departments (2010)	503	192

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PhD-granting physics departments typically have more faculty members than bachelor's-granting departments. The size of the department is one factor that affects whether or not a department will have a woman among its faculty members.

Simulations of the Effects of Department Size and Proportion of Women

In order to illustrate the effects of the number of faculty members and the overall proportion of women on the number of departments with no women, we present the results of simulations. The simulated outcomes in this paper are calculated using the binomial distribution. As noted earlier, the binomial distribution has two parameters: *n* and *p.* We use the binomial distribution to determine the number of women selected into a department consisting of a given total number of faculty members. The two parameters are *n* and *p* where

> *n* is the total number of faculty members in a given department and *p* is the overall proportion of women among all current physics faculty (or, the probability that a randomly selected faculty member is a woman).

The probability of getting exactly *k* women among *n* faculty members is given by $P(K = k) = \frac{n!}{k!(n-k)!} p^k (1-p)^{n-k}$.

In **Table 2**, we used the binomial distribution to calculate the probability that departments have same-sex faculties, given a certain number of faculty members in a department and given a certain percentage of women faculty members in the system. We picked the number of faculty members (*n*) to vary among 4, 6, 15, and 22. In this example, four- and six-member departments illustrate typical bachelor's-granting departments, while departments with 15 and 22 faculty members are illustrative of PhD-granting departments. We varied the proportion of women among all current faculty (*p*) from 11% to 50%. We use 50% here to illustrate the situation if half of all faculty members were women.

For physics departments that award a bachelor's degree only:

- 16% is the actual proportion of women among the faculty and
- 23% is the actual proportion of women among assistant professors.

For physics departments that award a doctorate:

- 11% is the actual proportion of women among the faculty and
- 20% is the actual proportion of women among assistant professors.

Physics departments that award only a bachelor's degree tend to have fewer faculty members.

Note that as the number of faculty members in a given department increases, the total probability that faculty members will be all the same sex decreases. Similarly, as the proportion of women overall increases, the total probability that a department has all faculty members of one sex decreases.

Table 2

Probability That Faculty is All Women or All Men

For Specific Department Sizes and % Women Overall

Total Number of Faculty Members in a Single Department (n)	Overall % Women Among All Faculty Members (p)	Probability That Department Is …		
		(A) All Women (%) (P(k=n))	(B) All Men (%) (P(k=0))	One Sex (%) (A+B)
4	16	0.1	50	50
4	23	0.3	35	35
4	50	6.25	6.25	12.5
6	16	≪ 0.1	35	35
6	23	< 0.1	21	21
6	50	1.6	1.6	3.1
15	11	≪ 0.1	17	17
15	20	≪ 0.1	4	4
15	50	≪ 0.1	≪ 0.1	≪ 0.1
22	11	≪ 0.1	8	8
22	20	≪ 0.1	1	1
22	50	≪ 0.1	≪ 0.1	≪ 0.1

When women are less than 50% overall, probabilities that departments are all male are much higher.

For physics departments that award a bachelor's degree only:

- 16% is the actual proportion of women among the faculty and
- 23% is the actual proportion of women among assistant professors.

For physics departments that award a doctorate:

- 11% is the actual proportion of women among the faculty and
- 20% is the actual proportion of women among assistant professors.

Physics departments that award only a bachelor's degree tend to have fewer faculty members.

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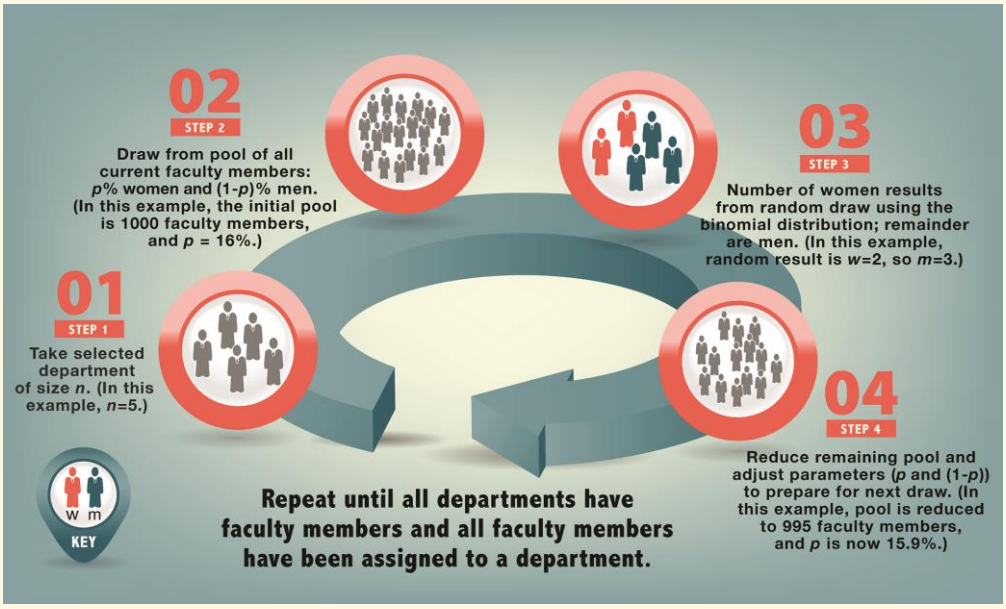
The effects of the number of faculty members on the probability that a department will have faculty members who are all the same sex helps explain why such a large percentage of bachelor's departments have no women. Bachelor's departments tend to be small; therefore, as we have seen in **Table 2**, there is a higher probability of these departments having no women.

To further illustrate the effects of department size, we use another example. We keep the proportion of women constant while varying only the size of the department. For illustration, consider keeping the proportion of women constant at 50% while varying only the size of the department. We simulate the random assignment of faculty members to departments of all one size. We repeated the simulation 500 times for each department size. The mechanics of the simulation are detailed in **Figure 1**, and the results are shown in **Figure 2** (on page 6).

Figure 1

The Simulation Process



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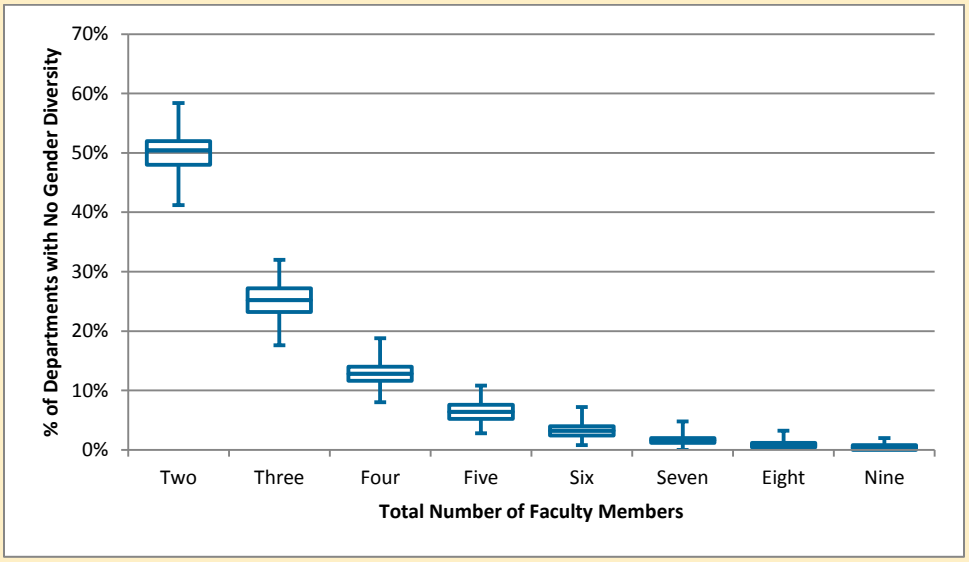
In our first simulation, *n* is constant. In our remaining simulations, *n* changes to reflect the actual profile of all physics departments.

As the results show (**Figure 2**), it is harder to achieve diversity in smaller departments than in larger departments. When we randomly assign 1000 faculty members — half men and half women — into 500 departments with two faculty members in each department, about half of the departments have no variation by sex. This is not surprising; if we toss a fair coin twice, we will get one head and one tail about half of the time. Of course, as we increase the size of the department, the results are increasingly likely to show faculty members of both sexes. In this example with half men and half women overall, only when we reach six faculty members or more is there no variation by sex in less than 10% of the departments. (With five faculty members we are under 10% most, but not all, of the time.)

Figure 2

Simulation Results: Faculty Variation by Sex in Departments of Uniform Size

Simulation Assumes Half of All Faculty Members Are Women



The box outlines the middle 50% of the results from 500 simulations with the bar indicating the median. Lines extend to the maximum and minimum values.

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Even if half of all faculty members are women, small departments are likely to have faculty members that are all the same sex.

Expected and Actual Proportions of Same-Sex Departments

We can continue to examine the effects of department size on the sex composition of physics departments by looking at data from the Academic Workforce Survey of physics departments, which AIP conducts every two years. In Tables 3 and 4, we show the actual distribution of the number of faculty members in each department, along with the probabilities of departments with same-sex faculties (calculated using the binomial distribution).

We can calculate the expected proportion of physics departments that have faculty members of only one sex using the binomial distribution.

In bachelor's-granting physics departments, the median number of professorial-rank faculty is four, and 16% of all professorial-rank faculty members are women. As shown in **Table 3**, combining the expected probability of departments that are same sex (Column C) with the actual proportion of departments of each size (Column B) yields an expected total of 49% of bachelor's-granting departments that will have same-sex faculties (total Column D). From the 2010 Academic Workforce Survey, we know that 48% of bachelor's-granting physics departments have no variation by sex (47% of these have no women and 1% have no men).

In PhD-granting physics departments, the median number of professorial-rank faculty is 22, and 11% of all professorial-rank faculty are women. As shown in **Table 4**, combining the data yields an expected total of 12% of PhD-granting departments that will have same-sex faculties. Currently, 8%

of PhD departments are same sex (all of these have no women). PhD-granting departments typically have more faculty than bachelor's-granting departments, so they are more likely to have both sexes represented among faculty members. Therefore, the expected percentage of same-sex departments is about the same as or higher than the actual percentage in both bachelor's- and PhD-granting departments.

Table 3

Expected Proportion of Departments With Same-Sex Faculties
Bachelor's-Granting Physics Departments Only, 2009-10 Academic Year

A	B	C	D
Number of Professorial Rank Faculty Members	Proportion of Bachelor's-Granting Departments (%)	Probability Department Has All One Sex* (%)	Expected Proportion of Same-Sex Departments (Column B * Column C) (%)
1	5	100	5
2	15	73	11
3	17	60	10
4	17	50	9
5	16	42	7
6	9	35	3
7	8	30	2
8	8	25	1
9	3	21	1
10	2	17	0
11	1	15	0
12	1	12	0
13	1	10	0
14	0.2	9	0
18	0.2	7	0
20	0.2	6	0
21	0.2	5	0
27	0.2	4	0
TOTAL	**100%**	-	**49%**

* The probabilities in Column C assume that 16% of the faculty members are women.
The values in Columns B and D may not sum to total shown due to rounding.
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Given the large number of small departments and the low representation of women among faculty members, we expect almost half of the bachelor's-granting physics departments to have same-sex faculties.

Next, we simulated the random assignment of a fixed number of men and women faculty into departments of varying sizes to take a closer look at how expected proportions of same-sex faculties match reality.

The simulations rely on the binomial distribution, which we have described previously. We simulate the assignment of men and women in professorial ranks to each department, varying *n* to account for the size of the current

department and *p* to account for the probability that a randomly selected faculty member is a woman. For the first bachelor's-granting department, *p* = 16%. For subsequent departments, the value of *p* changes dynamically to account for the number of men and women still remaining to be assigned.

Table 4

Expected Proportion of Departments With Same-Sex Faculties
PhD-Granting Physics Departments Only, 2009-10 Academic Year

A	B	C	D
Number of Professorial Rank Faculty Members	Proportion of PhD-Granting Departments (%)	Probability Department Has All One Sex* (%)	Expected Proportion of Departments with All One Sex (Column B * Column C) (%)
3	1	71	0.4
4	1	63	0.3
5	2	56	0.9
7	1	44	0.2
8	2	39	0.9
9	1	35	0.2
10	2	31	0.7
11	3	28	0.9
12	4	25	1.1
13	4	22	0.8
14	4	20	0.9
15	2	17	0.4
16	5	15	0.8
17	4	14	0.6
18	4	12	0.5
19	3	11	0.3
20	3	10	0.3
22 or more	53	Varies	2
TOTAL	**100%**	-	**12%**

* The probabilities in Column C assume that 11% of the faculty members are women.

The values in Columns B and D may not sum to total shown due to rounding.

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Even though the representation of women is lower in PhD-granting physics departments, the expected proportion of departments with same-sex faculties is lower than for bachelor's-granting departments because PhD departments have more faculty members.

For example, assume there are initially 1000 faculty members to be assigned to various departments, 160 women and 840 men. Then *p*, the probability that a randomly selected faculty member is a woman, is 160/(840+160) = 16%. However, *p* will change for the next department based on how many men and women are assigned to the current department. If there were two women and four men assigned to the first department, then *p* for the second department is 158/(836+158) = 15.9%. The fact that the first

department had two women assigned to it reduces the probability that a randomly selected faculty member in the second department is a woman.

Figures 3 and **4** (following pages) depict the results of 500 simulations of the random assignment of men and women faculty into professorial ranks at bachelor's- and PhD-granting physics departments. Recall that the actual percentage of bachelor's-granting departments that have no women is 47%. In over 74% of the 500 simulations, the percentage of bachelor's departments that had no women was *higher* than 47%.

These results suggest that bachelor's departments are actually placing women faculty members into *more* departments than if the distribution of women into departments were left to chance. Of course, this also means that, given the set number of women, there are more departments with only one woman than there would be if the distribution was purely random. Furthermore, our results suggest that the lack of women in bachelor's-granting departments is consistent with two facts:

- 16% of the faculty members in bachelor's departments are women, and
- bachelor's departments tend to have a small number of faculty members (median=4).

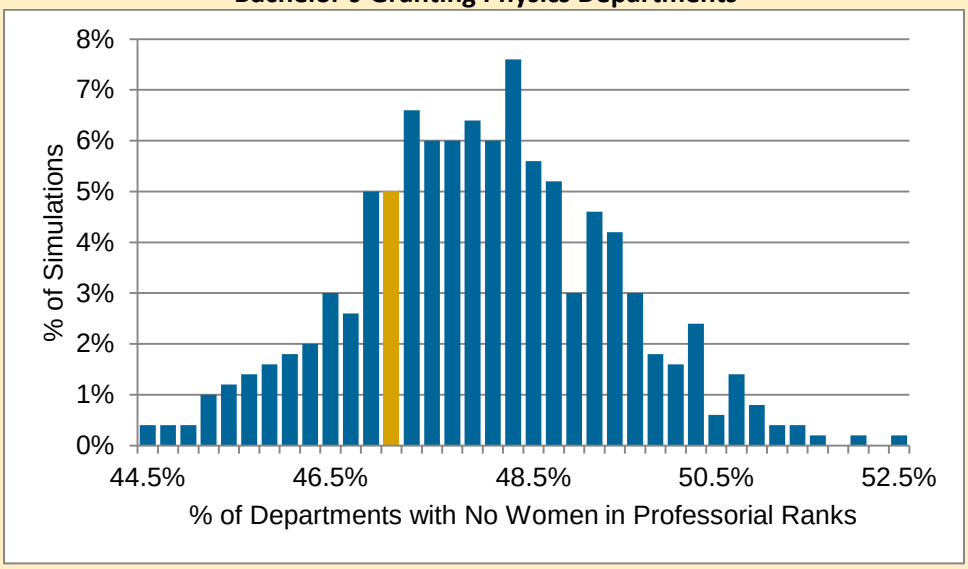
In our simulations, the expected proportion of departments with same-sex faculties was higher than the actual 74% of the time for bachelor's-granting physics departments and 99% of the time for physics departments which grant PhDs.

Again, recall that 8% of PhD-granting physics departments have no women. In 500 simulations of the assignment of professorial rank faculty members to PhD-granting departments, 99% of the time, *more* than 8% of the departments had no women (**Figure 3**). In other words, women faculty members actually are found in *more* PhD departments than one would expect. This indicates that PhD-granting departments overall are succeeding in getting women faculty members into a *higher* number of departments than we would expect based on the size of the departments and the percentage of women in the system.

We know that faculty members are not randomly assigned to departments. There are many factors that affect the makeup of a physics department, including factors the department can impact and factors beyond the control of the department. The department considers the ability of its infrastructure and setting to support an applicant's research, the fit of the applicant's research with the department's mission and existing faculty members' areas of expertise, the ability of the applicant to secure external funding, and a variety of other factors including personalities. The applicant also has many things to consider, including externalities such as family issues and competing offers — both within and beyond academia.

Figure 3

Simulation Results: Proportion of Departments With No Women in the Professorial Ranks
Bachelor's-Granting Physics Departments



In 370 of our 500 simulation runs, there were more bachelor's-granting physics departments with same-sex faculties than there are in reality.

The gold bar indicates the simulation results that mirror the actual proportion of departments with no women in the professorial ranks.

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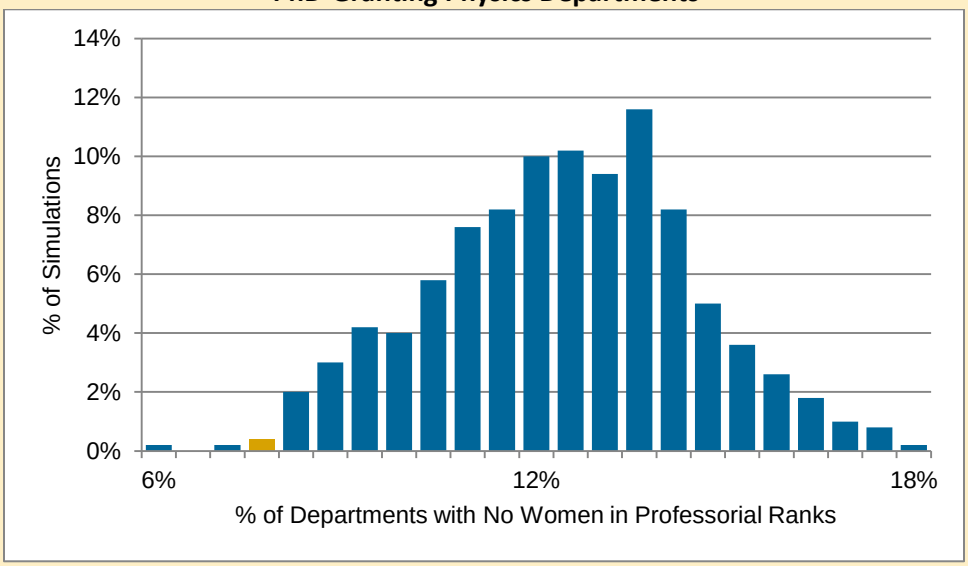
Figure 4

Simulation Results: Proportion of Departments With No Women in the Professorial Ranks
PhD-Granting Physics Departments



In almost all of our 500 simulation runs, there were more PhD-granting physics departments with same-sex faculties than there are in reality.

The gold bar indicates the simulation results that mirror the actual proportion of departments with no women in the professorial ranks.

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Our results suggest that there is no bias against hiring women in the system as a whole. This does not mean that selected individual departments do not discriminate or have environments that are less than welcoming to women. However, the lack of women in physics departments cannot be used as a measure of gender equity because the number of departments that have women is the result of:

- the number of faculty members in the single department and
- the overall proportion of women among all physics faculty.

This does not mean that selected individual departments do not discriminate or have environments that are less than welcoming to women.

What if Half of All Physics Faculty Members Were Women?

Even if half of all faculty members were women, we would still expect to find no gender variation in 20% of the bachelor's-granting physics departments — with 10% having no men and 10% having no women. We would expect almost all of the PhD-granting departments to include at least one woman and at least one man among the faculty (**Table 5**).

The percentage of women in physics has grown very slowly over the previous decades. Currently, about 20% of the assistant professors in PhD-granting departments are women, and about 23% are women in bachelor's-granting departments (**Figure 5**), which is higher than the percentage of women among recent PhD graduates. This is further evidence that there is no systematic bias against hiring women.

Table 5

Probability that Faculty is All Women or All Men For Specific Departments Sizes and % Women Overall

Department Profile Matches …	Overall % Women	Expected Proportion of Departments with Faculty Members which …	
		Are All the Same Sex (%)	Have Members of Both Sexes (%)
Bachelor's-Granting Departments	16	49	51
	23	37	63
	50	20	80
PhD-Granting Departments	11	12	88
	20	3	97
	50	<1	>99

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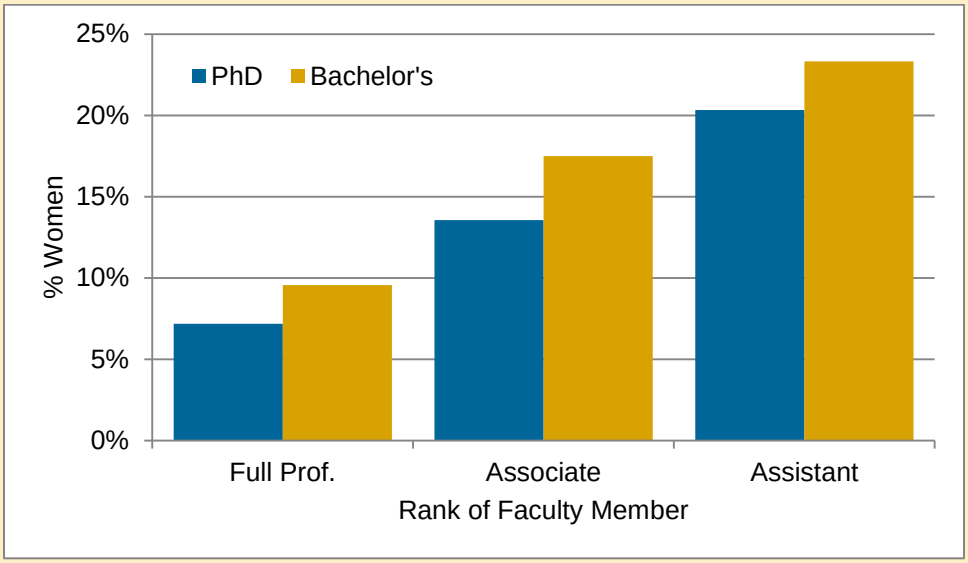
Because of the large number of small departments, even if half of all faculty members were women, we would still expect to see over 100 bachelor's-granting physics departments have same-sex faculties.

Figure 5

Proportion of Professorial–Rank Faculty Who are Women
Bachelor's- and PhD-Granting Physics Departments, 2009-10 Academic Year



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The proportion of women at the assistant professor rank in bachelor's-granting physics departments is actually higher than that of recent PhD graduates.

Conclusions

The sex composition of a physics department is the result of a multitude of events, some recent and some that go back many years. Based on these simulation results, though, we should not accept the absence of women among professorial-rank faculty in a single department to be *prima facie* evidence of a bias against women.

Instead, we would do well to consider departments' and institutions' environments in evaluating the situation of women in physics. Even in physics departments with women faculty members, women could experience hostile climates, lack of resources to do research, and limited professional opportunities, all of which can have a cumulative negative effect on their careers.

We must also recognize that having at least one woman among the faculty in more departments results in an increased number of women who are the *only* woman in their department.

We must also recognize that having at least one woman among the faculty in more departments results in an increased number of women who are the *only* woman in their department. Given the current representation of women among all physics faculty, this isolation of women faculty members is the, perhaps unintended, tradeoff that occurs when women, representing a small proportion of all physics faculty members, are found in more departments than expected. The only way to reduce the number of women faculty members who are the only woman in their department while continuing to have women in these departments is to increase the representation of women overall. However, even if women ultimately comprise half of all physics faculty members, we would still expect to find

some departments with no women among their faculty — and some with no men.

While counting the number of departments with no women is not a valid measure of gender equity, we do not mean to provide a convenient explanation for departments that have no gender variation. Instead, the issue of gender equity in physics is more complex and nuanced. It cannot be distilled into any single measure.

About the Academic Workforce Survey

The Academic Workforce Survey of physics departments has been conducted every two years since 1986. Every four years, we collect data on the number of women in each department by their rank. For the data used in this paper, we contacted each of the 758 departments that awarded at least a bachelor's degree in physics by e-mail, mail, and certified mail. Follow-up contacts were made for departments that had not yet responded. Data collection began in March 2010 and ended in July 2010. We received responses from 707 departments (93%). We offer our sincere gratitude to the responding departments. Without your help, we could not track these data or provide them to the community.

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