Understanding current causes of women's underrepresentation in science

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Explanations for women's underrepresentation in math-intensive fields of science often focus on sex discrimination in grant and manuscript reviewing, interviewing, and hiring. Claims that women scientists suffer discrimination in these arenas rest on a set of studies undergirding policies and programs aimed at remediation. More recent and robust empiricism, however, fails to support assertions of discrimination in these domains. To better understand women's underrepresentation in math-intensive fields and its causes, we reprise claims of discrimination and their evidentiary bases. Based on a review of the past 20 y of data, we suggest that some of these claims are no longer valid and, if uncritically accepted as current causes of women's lack of progress, can delay or prevent understanding of contemporary determinants of women's underrepresentation. We conclude that differential gendered outcomes in the real world result from differences in resources attributable to choices, whether free or constrained, and that such choices could be influenced and better informed through education if resources were so directed. Thus, the ongoing focus on sex discrimination in reviewing, interviewing, and hiring represents costly, misplaced effort: Society is engaged in the present in solving problems of the past, rather than in addressing meaningful limitations deterring women's participation in science, technology, engineering, and mathematics careers today. Addressing today's causes of underrepresentation requires focusing on education and policy changes that will make institutions responsive to differing biological realities of the sexes. Finally, we suggest potential avenues of intervention to increase gender fairness that accord with current, as opposed to historical, findings.

women in science | gender bias | child penalty | peer review

Since 1970, women have made dramatic gains in science. Today, half of all MD degrees and 52% of PhDs in life sciences are awarded to women, as are 57% of PhDs in social sciences, 71% of PhDs to psychologists, and 77% of DVMs to veterinarians.* Forty years ago, women's presence in most of these fields was several orders of magnitude less; e.g., in 1970 only 13% of PhDs in life sciences went to women (1). In the most math-intensive fields, however, women's growth has been less pronounced (2–4). Among the top 100 US universities, only 8.8–15.8% of tenure-track positions in many math-intensive fields (combined across ranks) are held by women, and female full professors number ≤10%. (*SI Text*, S1)

These figures reveal a problem, but what is its cause? Here, we consider one of the most common alleged causes–discrimination against women in the domains of: (*i*) manuscript reviewing, (*ii*) grant funding, and (*iii*) interviewing/hiring. We reprise the evidence for each and describe counterevidence. We conclude that past initiatives to combat discrimination against women in science appear to have been highly successful. Women's current underrepresentation in math-intensive fields is not caused by discrimination in these domains, but rather to sex differences in resources, abilities, and choices (whether free or constrained). Thus, current initiatives direct energy toward solving past problems rather than current ones. Women's underrepresentation today results from a complex set of interrelated factors, some of which society could meaningfully address if the focus was placed squarely on them. One key to such success is moving beyond historical issues and confronting current ones.

Claims of Discrimination Against Women Scientists

Recent scientific reports often assert that discrimination against female scientists in hiring, publishing, and funding is a cause of their underrepresentation:

> "Substantial research shows that resumes and journal articles were rated lower by male and female reviewers when they were told the author was a woman; similarly, a study of postdoctoral fellowships awarded showed that female awardees needed substantially more publications to achieve the same competency rating as male awardees" (5, p. 1933).

> "It is now recognized that biases function at many levels within science including funding allocation, employment, publication, and general research directions" (6, p. 1247).

> "Research has pointed to bias in peer review and hiring. For example, Wennerås and Wold found that a female postdoctoral applicant had to…publish at least three more papers in a prestigious science journal or an additional 20 papers in lesser-known specialty journals to be judged as productive as a male applicant….The systematic underrating of female applicants could help explain the lower success rate of female scientists in achieving high academic ranks" (7, p. 24).

> "An impressive body of controlled experimental [research]…shows that, on the average, people are less likely to hire a woman than a man with identical qualifications, are less likely to ascribe credit to a woman than to a man for identical accomplishments…" (8, p. S2).

Such claims of discrimination against women are consistent with claims of glass ceilings, reduction of authorship credit and pay for comparable work, smaller laboratory space, and fewer research resources (9–11). For example, economists analyzing auditions for orchestras found that switching to blind auditions in which juries could not see applicants reduced discrimination against women, explaining one-third of the increase in the proportion of women hired after blind auditions (12). Other examples of discrimination in nonmath fields are similarly striking, e.g., correlations between masculineness of women's first names and likelihood of being awarded judgeships (13), downgrading of psychologists' and sociologists' curriculum vitae when they bear a woman's name (14, 15), or discriminatory pay for female attorneys (16). This evidence from nonmath fields raises the specter that similar biases explain the current dearth of women in math-intensive fields. Below, we describe empirical evidence for claims of discrimination in the domains of publishing, grant reviewing, and hiring. We find the evidence for recent sex discrimination–when it exists–is aberrant, of small magnitude, and is superseded by larger, more sophisticated analyses showing no bias, or occa-

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*Feeder pipelines are sometimes even higher than the numbers earning PhDs, indicating some leakage. For example, slightly more than 60% of B.S. degrees in biology are earned by women, so 52% female PhDs represents some pipeline leakage from the 60% of BS degrees.

sionally, bias in favor of women. Although real barriers are still faced by women in science, especially mathematical sciences, our findings suggest that historic forms of discrimination cannot explain current underrepresentation, and that resources should be redirected toward current rather than historical causes of women's underrepresentation in math-based careers.

Discrimination Against Women in Journal Reviewing

The question of whether sex discrimination exists in getting work published is ideally answerable by examining manuscript acceptance rates of men vs. women, holding constant quality of work. However, quality of work is influenced by available resources. Comparing women and men with comparable resources, we find no sex discrimination in publishing (below). However, a secondary issue is whether resources themselves are, in fact, evenly distributed between the sexes. The answer is that they are not, for a complex constellation of reasons, such as women being more apt to occupy teaching-intensive positions, part-time positions, etc. Thus, the attention devoted to righting perceptions of sex discrimination in reviewing of manuscripts, which as we show, does not in fact exist (*SI Text*, S2), focuses on a spurious issue and detracts from the very real problem that does plague women in publishing—the fact that women more often than men lack resources necessary to produce high-quality work.

Budden and her colleagues published several analyses of gender bias in manuscript reviewing by undergraduates, graduate students, postdocs, and journal reviewers (6, 17–19). In one, they analyzed journal acceptance rates for manuscripts submitted by women to *Behavioral Ecology* after it began blind peer review (18). Acceptance rate for female first-authored manuscripts increased by 7.9% in the 4 y after the onset of blind review, compared with the 4 y prior, suggesting that when reviewers were aware of authors' sex, they were less likely to accept women's manuscripts. Critics argued that the difference between pre- and post-blind-review acceptances cannot be tied to sex discrimination, criticizing this finding on statistical grounds, and noting that increased acceptance rates for women occurred during this period at six other ecology and evolution journals that did not implement blind review and that increases were already apparent in the decade before implementation of blind reviewing at *Behavioral Ecology* (20–22). Whittaker (22) analyzed 1,140 manuscripts submitted to the *Journal of Biogeography* and found no difference in the acceptance/rejection ratio for male and female authors ($x^2 = 1.0637$, $p = 0.3024$); he also criticized Budden et al.'s statistical procedures. Others did not replicate Budden et al.'s claim of sex discrimination with other journals (see below). In response, Budden et al. argued such criticisms cannot explain their full findings, although they acknowledged their inability to rule out alternative explanations due to limited data (19).

Less-often cited analyses by Budden et al. did not find evidence of sex discrimination. One (23) compared publication success rates for 2,680 papers with male vs. female first authors at five ecology and evolution journals (with seven editors). There was no sex difference in overall acceptance rates; although one of seven editor's data from one of five journals initially appeared to favor males, this impression was not borne out by more rigorous log-linear analyses, leading to the conclusion that "there is no significant interaction between journal and author gender in their effect on whether manuscripts are accepted for publication" (ref. 23, p. 350). In another study by Budden and her colleagues (17), 989 raters (undergraduates to postdocs) were given an identical manuscript with either no name, author's first initial only, a male name, or a female name. This study also found no sex discrimination. To recap, there is evidence of bias from one of Budden's studies (18), but criticisms have been published on various grounds (20–22); other journals show no such bias (24, 25); and Budden has acknowledged limitations. Further, archival acceptance data from various journals strongly suggest no sex differences (see below).

Another source of evidence is aggregate productivity measures: Are women as likely as men to publish? Many sources of data span numerous fields and cohorts. They show that women are as successful at publishing as men, when comparisons are between men and women with similar resources and characteristics. (Comparing people possessing unequal resources is not a test of discrimination, but a demonstration of limitations imposed by a lack of resources, and women tend to have jobs that provide fewer resources; e.g., teaching- vs. research-intensive positions.) The editors of *Nature Neuroscience* analyzed acceptance rates for 449 authors (24) and found that acceptance rates were statistically indistinguishable between the sexes, $p = 0.811$, regardless of how the data were parsed. Other journals (e.g., *Cortex*) have also reported equal acceptance rates (25).

Others have undertaken sophisticated analyses of archival data showing that any sex difference in productivity is due to differences in structural variables that, although correlated with sex, are causally unrelated to it (26–27) because the same fate befalls male authors with similar structural characteristics. Thus, although such variables (e.g., working at teaching-intensive colleges) affect women more often than men, they hinder men's productivity equally. Scientists' publications increase after moving to more prestigious institutions with greater resources (27). In this analysis, males produced 30% more publications than women, but when men tenured at R1 universities were compared with women tenured at R1 universities, the gap fell to 8%, and the difference between men and women full professors at R1s was <5%.

Thus, the critical variable is not sex per se, but rather access to resources, which correlates with sex because women are more likely to work as adjuncts or at teaching-intensive institutions with limited resources (*SI Text*, S2). As evidence, a longitudinal analysis of faculty in 1969, 1973, 1988, and 1993 showed sex differences in productivity steadily declined—from a female:male ratio of 0.580:1 in 1969 to 0.817:1 in 1993 (26). The primary factor affecting women's productivity was structural position. When type of institution, teaching load, funding, and research assistance were factored in, the productivity gap completely disappeared (which is not to say discrimination has not influenced these factors in the real world): "There is very little direct effect of sex on research productivity. . .. men generally have positions superior to those of women, although structural differences by gender have appreciably declined over time. Once sex differences in such positions and resources are taken into account, net differences between men and women in productivity are nil or negligible" (ref. 26, pp. 863–864).

Similarly, a National Research Council task force concluded that productivity of women science and engineering faculty increased over the last 30 y and is now comparable to men's, the critical factor affecting publications being access to institutional resources (28). Finally, many others also report no sex differences in productivity, controlling for structural variables confounded with sex (e.g., refs. 7 and 8).

In sum, when publication data are controlled for structural position, ensuring that sex differences in manuscript acceptance rates are not conflated with sex differences in resources, there is no difference between the sexes (*SI Text*, S3). Although structural differences present real barriers for many women—and some men—journal reviewers do not reject papers because they are written by women. The preponderance of evidence, including the best and largest studies, indicates no discrimination in reviewing women's manuscripts: Given equivalent resources, men and women do equally well in publishing. A key issue, separable from sex discrimination in manuscript evaluation, is why women occupy positions providing fewer resources and what can be done about this situation. This situation is caused mainly by women's choices, both freely made and constrained by biology and society, such as choices to defer careers to raise children, follow spouses' career moves, care for elderly parents, limit job searches geographically, and enhance work-home balance. Some of these choices are freely made; others are constrained and could be changed (3).

Discrimination Against Women in Grant Funding

Another domain of alleged sex discrimination is grant and fellowship reviews. In an influential article in *Nature* (cited 212 times),[†] Wennerås and Wold (29) reported that when reviewers

[†]As a more important indicator of its influence, this article is frequently invoked as evidence by proponents of interventions such as NSF's $130 million ADVANCE initiative.

judged postdoctoral fellowship applications to the Swedish Medical Research Council (MRC) in 1995, the conversion of data into subjective scores was highly prejudiced against women. A *Nature* commentary stated: "The response across the world could be measured on the Richter scale after the revelation that the (MRC) exercised prejudice in its allocation of research fellowships. Six months later, the implications are still being discussed in the newspapers and on radio and TV" (ref. 30, p. 204). The claim of discrimination was based on 62 applications submitted by men and 52 by women: 16 men were funded (25.8%) vs. 4 women (7.7%). Evidence of bias was based on analyses of reviewers' scores versus objective data (e.g., publications, citations). Reviewers judged each applicant on scientific competence, proposal relevance, and methodology. Women received somewhat lower mean scores than men in all three categories, the largest discrepancy being in scientific competence—2.46 vs. 2.21. The total impact score was most predictive of reviewers' ratings of scientific competence (r^2 = 0.47): A woman needed a 2.6 times higher "total impact measure" score than a man to be judged as competent.

To determine whether women and men were judged equally, Wennerås and Wold (29) assumed an applicant's scientific competence is linearly correlated with number and quality of published journal articles, leading to an examination of total number of publications, total number of first-author publications, total citations, total impact measure, first-author impact measure, and first-author citations. They reported "a female applicant had to be 2.5 times more productive than the average male applicant to receive the same competence score" (ref. 30, p. 342). The most productive female applicants—those with 100 or more impact points (based on number of publications and how frequently the journals are cited)—was the only group of women judged as competent as men, but only the least productive men who had fewer than 20 impact points. However, the authors' conclusion of bias against women was challenged on statistical, methodological, and conceptual grounds (*SI Text*, S4). Analyses of funding societies in Europe and North America failed to find bias against female applicants during this same period (1994–1995). One analysis of nearly 3,000 grant applications to the British Wellcome Trust and MRC for the period 1993–1996 revealed no evidence of sex bias in approval rates (31). Another reported no sex bias in grant approvals to the UK Biological Sciences Research Council (32). A third (33) reported results of ≈8,000 grant applications to the MRC of Canada, also failing to find sex differences. Although there are occasional instances of sex effects in these reports, they are rare, of small magnitude, and are as often in favor of women as against them; the largest aberrations were not close to Wennerås and Wold's finding (29) that women had to be 2.5 times more productive than men to obtain similar scores.

Consider that Dickson (32) reported that in 1996, the success rates for male and female grant applicants to the UK's Biotechnology and Biological Sciences Research Council were 24% and 19%, and 26% and 29% to the MRC, respectively. Grant et al. (31) reported that "the award rates for both sexes are approximately the same...Neither is there any evidence that women need a more impressive publication record than men to be successful in either organization's competitions" (p. 438). In fact, successful female candidates for project grants published on average 11.2 papers vs. 13.8 papers by males; successful female candidates for senior research fellowships published 11.8 papers vs. 14.3 for men.

In Canada, Friesen (33) found that, with one exception, grants were also gender-neutral: For the largest program, the success rates for men and women were 26.6% and 25.4% (n.s.). For the prestigious MRC-Canada Scholarship awards, which provided five years of salary for new PhDs, there was likewise no significant sex difference (14% for men vs. 16.6% for women). The sole sex difference favoring men was for the category of PhD students doing postdoc training and health professionals undertaking research training: 16.3% for men vs. 12.9% for women ($p < 0.05$). This difference is small, and of five competitions, two had virtually identical approval rates. Finally, Sandstrom and Hallsten (34) analyzed more recent data from the Swedish MRC and found that the gender bias reported by Wennerås and Wold (29) had reversed itself, so that there was a small but significant effect in favor of funding women's grants compared to men's with the same score. They analyzed 280 grant applications in 2004, 118 from female principal investigators, and found no evidence of gender bias: "Surprisingly, none of the productivity measures interact with gender: Male and female PIs are judged similarly with reference to productivity. When we control for all productivity measures and interactions...It appears that female PIs receive a bonus compared to male PIs" (34, p. 186). Perhaps this lack of sex difference is due to Wennerås and Wold's 1997 paper's impact, but this possibility does not explain why even larger, more encompassing studies preceeding theirs found no sex differences.

Thus, a decade after Wennerås and Wold's report (29), the Cochrane Methodology Review Group concluded that other than Wennerås and Wold's study, "a number of other studies carried out in similar contexts found no evidence of (sex discrimination)" (35, p. 2). However, perhaps studies with samples big enough to use the most sensitive measurement framework might unearth sex differences. It is especially useful, therefore, to examine studies meeting this standard. Six large-scale analyses have been published, on net providing compelling counterevidence to sex discrimination claims.

The first large-scale analysis (36) assessed gender bias at the National Science Foundation (NSF), the National Institutes of Health (NIH), and the US Department of Agriculture. This study concluded there was no gender bias in awarding of grants at these three federal agencies (*SI Text*, S5). At all three agencies, which fund tens of thousands of US scientists, men's and women's grants were approved at the same rate. [Relatedly, Leboy's (37) much smaller report of success rates for first-time RO1 grants at the National Institutes of Health for men and women revealed identical success rates for new submissions between 1998–2004 and very similar continuation grants by 2004.] Clearly, female PIs did not have to be 2.5 times better than males to be approved.

The second large-scale analysis is based on the Australian Research Council, which processes >3,000 applications annually in all areas of science. Marsh and his colleagues published several analyses of these data, using sophisticated measurement frameworks (38–40). In a multilevel analysis of 10,023 reviews by 6,233 reviewers of 2,331 proposals (38, 39), they found that although only 15.3% of applicants for grants were female PIs, their success was almost perfectly proportional (15.2%). When sex of only first-named investigator was considered, the success rate was identical: 21% both for men and women. Detailed analyses of second- and third-named researchers also indicated an absence of sex differences in success as did analyses based on mean external ratings and final panel committee ratings (38). No gender effect was found in any of the nine disciplines, and there was no gender bias as a function of reviewer or applicant sex or their interaction. [Subsequently, Marsh et al. (39) extended these results, again reporting no sex differences in approval rates that again generalized across disciplines, as well as to reviewers nominated by PIs vs. chosen by the agency, and to the country of the reviewer.]

The third large-scale analysis provides an exception to the consistent failure to find sex differences. Bornmann and Daniel (41) examined 1,022 applications for predoctoral fellowships and 134 for postdoctoral fellowships to a German Foundation between 1985 and 1990. They found no evidence for gender bias in approving postdoc fellowships, but evidence for bias in approving pre-PhD fellowships, with males more likely to be approved (*SI Text*, S6). A follow-up study by Bornmann and his colleagues (42, 43) used a sophisticated multilevel approach to a metaanalysis, based on their comprehensive collection of studies of peer reviews for grants. This time Bornmann found a difference in favor of men, albeit extremely small—an effect size of <0.04 (an odds ratio of only 1.07:1.00). Only 1 of 66 sex-difference effect sizes was significant. Once again, no bias was found for postdocs, the group studied by Wennerås and Wold (29).

The fourth large-scale study was based on all grant proposals submitted to the Economics Program at NSF during the years 1987–1990. Broder (44) analyzed 6,764 reviews. Consistent with the dearth of women economists in the late 1980s, only 9.3% of the PIs and 7.6% of the reviewers were women. However, Broder found

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female PIs fared well when rated by male reviewers at NSF, but less well when rated by female reviewers, a finding she suggested may have worked against increased representation of women.

The fifth large-scale analysis attempted to reconcile contradictory findings by Marsh et al. vs. Bornmann et al. These teams joined forces and conducted a reanalysis of Bornmann and Daniel's (41) data to resolve their differences. Marsh, Bornmann et al. (45) applied the most powerful analytic approach to date, leading both camps to agree that there was no evidence of sex differences favoring men in any category. In fact, they found evidence favoring women, after controlling for discipline and country. These results were robust, with little study-to-study variation and a lack of interactions: "This noneffect of gender generalized across discipline, the different countries (and funding agencies) considered here, and the publication year" (45, p. 1311). Regarding sex differences in approval of fellowship applications, there was a small but statistically significant difference in favor of men. This finding is the closest any of the analyses have come to replicating Wennerås and Wold (29) (*SI Text*, S7), although the magnitude of this finding was not nearly as pronounced. The joint team interpreted this single finding in favor of men as an aberration from an otherwise unambiguous pattern of no sex advantages or even slight female advantage, and the lack of sex differences generalized over country and discipline (45).

Finally, the sixth large-scale analysis of funding was conducted on >100,000 NIH submissions in six biomedical categories between 1996 and 2007 (46). The percentages of submissions funded were largely equivalent, with men favored slightly in some categories and women favored in others, leading the authors to conclude: "Men and women have near-equal NIH funding success at all stages of their careers, which makes it very unlikely that female attrition is due to negative selection from NIH grant-funding decisions" (p. 1473).

To recap, the weight of evidence overwhelmingly points to a gender-fair grant review process. There are occasional small aberrations, sometimes favoring men and sometimes favoring women; all of the smaller-scale studies failed to replicate Wennerås and Wold's provocative findings, and all but one of the large-scale studies did as well—however, this one study was reversed after a more ambitious joint reanalysis (45). Despite this overwhelming counterevidence, numerous organizations continue to suggest grant review is discriminatory (47), thus diverting attention from legitimate factors limiting women's participation in math-based careers.

The pattern of null sex effects reviewed above is based on funding decisions since the mid-1980s. This period may differ from that >25 y ago. Perhaps sexism was more common at agencies then and women's grants had to be superior to men's to be funded. Such sexism would be unsurprising given other evidence of sexism from this earlier era. Still, sexist reviews cannot be the source of today's dearth of women entering assistant professorships in math-intensive fields. In contrast to claims of antifemale bias among funding agencies quoted in the Introduction, this review indicates a level playing field over the last two decades.

Discrimination Against Women in Hiring

If the underrepresentation of women in math-intensive fields is not due to biased journal or grant reviews, perhaps it results from biased interviewing and hiring decisions? A study of mock-search-committee recommendations for hiring of psychology professors (15) is often invoked for suspecting it does. In this study, 238 psychologists reviewed fictitious assistant professor candidates and more advanced job seekers. The authors used the same CV, varying applicant sex, and found that both female and male reviewers favored CVs with male assistant professor names, although they did not favor men for the more advanced post. Similarly, women on business teams receive less credit than men for identical work. For stereotypically male tasks, if there is ambiguity about the quality of a woman's contribution to a joint task, it is downplayed (48). Both male and female judges rated a hypothetical worker's performance worse when they thought the worker was female. These results, coupled with findings that nonblind auditions for positions in orchestras discriminated against women (12) and that 18-y-old college males favored resumes with male names for summer jobs when they were similar, although not identical to, those with female names (14), suggest comparable discrimination may be responsible for the dearth of women entering math-intensive fields.

Although none of this evidence involved discrimination in math-intensive fields, it would be unlikely for sex discrimination to occur in all fields except math-intensive ones. A Government Accounting Office (GAO) report notes that women in math-intensive fields express feelings of isolation, dissatisfaction, and discrimination, "assertions that we also heard during many of our site visits to selected campuses" (ref. 49, p. 4).[‡] This report touches on several factors supported by various analyses as being relevant to women's underrepresentation (50). These factors include women being more likely to prefer working fewer hours and at part-time positions to achieve work-family balance. Although 77% of female and 81% of male graduate students believed a full-time career is "important" or "extremely important" (51), sex differences emerged after additional questioning, with 31% of women (vs. only 9% of men) feeling that working part time for a period is "important" or "extremely important". For having a permanent part-time career, the respective proportions were 19% for women and 9% for men (51). Similarly, in the United Kingdom for 2006–2007, female academics were significantly more likely than males to work part-time, 41.8% vs. 26.8% (25).

Such sex differences reflect preferences and choices, whether freely made or constrained by gendered expectations, and result in more women in teaching-intensive, part-time posts where research resources are scarce. Relatedly, the GAO report mentions studies of pay differentials, demonstrating that nearly all current salary differences can be accounted for by factors other than discrimination, such as women being disproportionately employed at teaching-intensive institutions paying less and providing less time for research. Historically, however, this was not true; women, particularly senior women, lagged behind men in pay and promotion (52, 53) (*SI Text*, S8). Ginther and Kahn (54) analyzed promotion and pay data, noting that historic asymmetries favoring males largely disappeared by the early 2000s, with current asymmetries due to nongender factors. Others have also found that after controlling for structural variables such as status of university, discipline, and presence of young children (which affects women disproportionately), there is no evidence of discriminatory treatment, because women and men in the same circumstances (e.g., same type of institution, discipline, and amount of experience) fare equivalently. Again, although these variables affect men and women similarly, they disadvantage women more in practice, because more women work at teaching-intensive jobs. A National Center for Education Statistics study found that among full-time faculty, women were more likely to work in 2-y institutions (33% vs. 23%), and men in research universities (20% vs. 14%). Whether this is a consequence of choices freely made, or constrained by gendered expectations related to work-family balance coupled with inflexibility in tenure-track timetables and employment options, is worthy of study.

Finally, an in-depth analysis of academic interviewing, hiring, institutional resources, and climate at R1 universities in six areas of natural science by an NRC task force (55) found that, among PhDs applying for tenure-track jobs, women were slightly more likely than men to be invited to interview and offered jobs: "If women applied for positions at R1 institutions, they had a better chance of being interviewed and receiving offers than male job candidates" (ref. 55, p. 5). These results are inconsistent with initiatives promoting gender sensitivity training for search committees and grant panels, which assume bias in funding and hiring of women (ref. 47, also see refs. 11, 56, and 57). Such initiatives target historical rather than current problems facing women scientists.

[‡]Analyses of >8,000 University of California graduate students' responses by Mason and Goulden (50) document the important role played by family formation in female graduate students' decisions to switch out of tenure-track careers in science. For example, married female doctoral students with children are 35% less likely to enter a tenure-track position after receiving a Ph.D. than married men with children and they are 27% less likely than men to achieve tenure. See http://ucfamilyedge.berkeley.edu/grad%20life%20survey.html.

Conclusion: Redirecting Energies Toward Today's Causes of Underrepresentation

Despite frequent assertions that women's current underrepresentation in math-intensive fields is caused by sex discrimination by grant agencies, journal reviewers, and search committees, the evidence shows women fare as well as men in hiring, funding, and publishing (given comparable resources). That women tend to occupy positions offering fewer resources is not due to women being bypassed in interviewing and hiring or being denied grants and journal publications because of their sex. It is due primarily to factors surrounding family formation and childrearing, gendered expectations, lifestyle choices, and career preferences—some originating before or during adolescence (3, 50, 54, 58) (*SI Text*, S9)—and secondarily to sex differences at the extreme right tail of mathematics performance on tests used as gateways to graduate school admission (*SI Text*, S10). As noted, women in math-intensive fields are interviewed and hired slightly in excess of their representation among PhDs applying for tenure-track positions. The primary factors in women's underrepresentation are preferences and choices—both freely made and constrained: "Women choose at a young age not to pursue math-intensive careers, with few adolescent girls expressing desires to be engineers or physicists, preferring instead to be medical doctors, veterinarians, biologists, psychologists, and lawyers. Females make this choice despite earning higher math and science grades than males throughout schooling" (3).

Although women earn a large portion of undergraduate degrees in all science and math fields, disproportionately fewer matriculate in math-intensive graduate fields, preferring biology, medicine, and nonscience fields (law, humanities)—even when math ability is held constant. Of women who matriculate in math-intensive graduate fields, more drop out or change majors. Even among those who complete doctorates in math fields, fewer apply for tenure-track posts than do male counterparts. And the leakage of women continues even after starting careers as assistant professors—especially in math and physical sciences, and this trend continues as women advance through the ranks:

> "Although the reasons for this attrition are not well understood, it appears to have less to do with discrimination or ability than with fertility decisions and lifestyle choices, both freely made and constrained. The tenure structure in academe demands that women having children make their greatest intellectual contributions contemporaneously with their greatest physical and emotional achievements, a feat not expected of men. When women opt out of full-time careers to have and rear children, this is a choice—constrained by biology—that men are not required to make" (3, p. 4).

To the extent that women's choices are freely made and women are satisfied with the outcomes, then we have no problem. However, to the extent that these choices are constrained by biology and/or society, and women are dissatisfied with the outcomes, or women's talent is not actualized, then we most emphatically have a problem. With a redirection of resources, this problem might be addressed by education and outreach to young women and girls and to academic administrators. Past strategies to remediate women's underrepresentation can be viewed as a success story; however, continuing to advocate strategies successful in the past to combat shortages of women in math-based fields today mistakes the current causes of women's underrepresentation.

If not discrimination, what is the cause of women's underrepresentation? Today, the dearth of women in math-based fields is related to three factors, one of which (fertility/lifestyle choices) hinders women in all fields, not just mathematical ones, whereas the others (career preferences and ability differences) impact women in math-based fields. Regarding the role of math-related career preferences, adolescent girls often prefer careers focusing on people as opposed to things, and this preference accounts for their burgeoning numbers in such fields as medicine and biology, and their smaller presence in math-intensive fields such as computer science, physics, engineering, chemistry, and mathematics, even when math ability is equated. In a recent metaanalysis of >500,000 participants, the male-female effect size for preferring people vs. things overall was $d > 0.90$, and for engineering, 1.1, both substantial differences (59). One strategy to broaden girls' interests and aspirations involves providing them with realistic information about career opportunities and exposing them to role models in math-based fields. This intervention is not meant to dissuade girls from aspiring to be physicians, veterinarians, and biologists, fields in which women are becoming a majority, but rather to ensure they do not opt out of inorganic fields because of misinformation or stereotypes.

Regarding the role of math-ability differences, potentially influenced by both socialization and biology, twice as many men as women are found in the top 1% of the math score distribution (e.g., SAT-M, GRE-Q). A 30-y study of 1.6 million talent search participants revealed the male-female ratio of SAT-M scores in the top 0.01% has remained relatively stable since the mid-1990s at roughly 4:1 (60). This upper-tail difference is more pronounced for spatial ability (61) due partly to sex differences in variances in cognitive abilities (4). However, ability differences are a secondary explanation for the dearth of women in math-intensive fields because, even given these differences, we would still expect more women in these fields (e.g., a 4:1 ratio would engender 20% female professors in, say, engineering, and a 2:1 ratio would lead to 33%, whereas actual percentages of women are lower (62; *SI Text*, S10).

The third factor influencing underrepresentation affects women in all fields: fertility choices and work-home balance issues. However, this challenge is exacerbated in math-intensive fields because the number of women is smaller to begin with. Attrition at each stage (from undergraduate to graduate school to tenure track) further reduces an already small number. There are significant sex differences in hours worked and lifestyle preferences (58), and having children early in one's career exerts more downward pressure on pretenure women than men (4, 52, 53). The tenure system has strong disincentives for women to have children; these disincentives are why more women in the academy are childless than men, and even women on tenure track with children are twice as likely as men to say they had fewer children than desired (50). Not only is it more common for male academic scientists to have children than for female scientists, but males with children are more likely to be tenured than females with children. Compared with males, new female PhDs are less likely to apply for tenure-track posts; and among those who do apply, females are more likely to terminate for family reasons (55). The GAO report (49) noted that many women PhD students stated during compliance visits that they would not seek tenure-track positions (*SI Text*, S11). In sum, the most salient reasons for women's underrepresentation today are career preferences and fertility/lifestyle choices, both free and constrained.

The GAO report lists strategies, such as stopping tenure clocks for family formation and tenure-track positions seguing from part-time to full-time. Gender Equity Committees have suggested adjusting the length of time to work on grants to accommodate child-rearing, no-cost grant extensions, supplements to hire postdocs to maintain momentum during family leave, reduction in teaching responsibilities for women with newborns, grants for retooling after leaves of absence, couples-hiring, and childcare to attend professional meetings (47, 50, 63). The UC-Berkeley's "Family Edge" provides high-quality childcare and emergency backup care, summer camps and school break care, and reentry postdocs and instructs committees to ignore family-related gaps in CVs. Research into these strategies is needed to identify which are promising.

Federal agencies and universities could play an important role by funding studies on the differing lifecourses of women's and men's careers to determine whether the traditional timing of hiring, tenure, and promotion may deny society and science the contributions of talented women. Perhaps women in scientific fields generally have greater impact later in their careers when family needs are less intense, even if they were less productive earlier because of family-balancing conflicts, as research has shown in biology (64). If this finding can be generalized to today's cohort of women in math-intensive fields, universities might explore options for offering women part-time tenure-track jobs (with concomitantly longer periods of time in which to amass a tenure portfolio), posts that could segue to full-time once women were ready. However, implementing such flexible options will require motivation and commitment of resources, and raises important questions that research will need to resolve (e.g., the impact on graduate students and postdocs working with part-time faculty; ways to "game" the part-time option for tenure). The linear career path of the modal male scientist of the past may not be the only route to success, and departments and universities should be encouraged and funded to experiment with alternate lifecourse options. A partnership between the academy and federal funding agencies could be instrumental in researching such alternatives.

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