Why So Few Women in Mathematically Intensive Fields?

STEPHEN J. CECI and WENDY M. WILLIAMS

Abstract

Women have made huge gains in all fields of science over the past four decades, greatly increasing their presence in PhD programs and in postdoctoral positions. But, their progress has been greater in some fields than others. Although women constitute a critical mass of faculty in fields such as biology, medicine, psychology, veterinary science, and sociology, they continue to be underrepresented in mathematically intensive fields such as engineering, physics, chemistry, economics, computer science, and mathematics. In this essay, we describe both data and argument pertinent to women's underrepresentation, organized around three alleged causes. After reviewing these three causes, we conclude that neither sex differences in mathematical and spatial ability, nor the often-alleged bias against women in science, can explain their dearth, whereas choices and family formation plans go a long way toward doing so.

WHY SO FEW WOMEN IN MATHEMATICALLY INTENSIVE FIELDS?

That women are underrepresented in math-intensive fields is not controversial—all who are familiar with the data have been aware of the dearth of women in mathematics-based fields for many decades:

There is agreement that women are underrepresented in all math-intensive fields in the academy: in geoscience, engineering, economics, math and computer science, and physical science (so-called GEMP) in 2010, women comprised only 25–44% of tenure-track assistant professors and 7–16% of full professors (authors' calculations based on the NSF 2010 Survey of Doctorate Recipients). But there is heated debate over why women are so conspicuously absent in these fields compared to social and life sciences, where the comparable figures are 66% of assistant professorships in psychology, 45% in social science (excluding economics), and 38% in biology; for full professors, the figures are 35%, 23%, and 24%, respectively. (Ceci, Ginther, Kahn, & Williams, 2014)

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In this Emerging Trends essay, we review and analyze reasons for the shortage of women in math-intensive fields, beginning with the claim that women's underrepresentation can be explained by sex differences in mathematical and spatial ability favoring males, coupled with bias against females in myriad forms. Following our presentation of the argument and evidence in favor of these alleged causes, we present evidence suggesting that they cannot explain women's underrepresentation in math-intensive careers and that other causes are more consistent with the data. We begin, however, with an acknowledgment that despite their current underrepresentation in math-based fields, women have made tremendous progress over the past four decades, sometimes quadrupling their presence (Ceci *et al*., 2014).

WHAT ARE THE CAUSES OF WOMEN'S CURRENT UNDERREPRESENTATION IN MATH-INTENSIVE FIELDS?

If we had written this essay many years ago, our answer would differ from what we provide here. This is because the trends are changing fast, and today they look very different from the past. Even a decade ago, the data looked somewhat different, and data more than a decade old are rapidly becoming obsolete. Below, we address three broad claims for women's underrepresentation in mathematically intensive careers: (i) males outperforming females in spatial and mathematical domains, resulting in fewer females in the extremely highly math-talented level needed for admission to graduate programs and beyond; (ii) biases against hiring of mathematically capable female applicants and bias in evaluating their work-products (e.g., journal submissions and grant applications), and (iii) sex differences in preferences and choices that lead men and women down different career paths even when they have comparable mathematical talent. Our analysis is based on the most current findings.

SEX DIFFERENCES IN MATHEMATICAL AND SPATIAL APTITUDE

Some have suggested that the shortage of women in math-intensive fields is rooted in aptitude differences that are visible among males and females very early in life and which accumulate over the lifecourse. We have reviewed this argument in detail elsewhere, and the interested reader can find the relevant references and findings there (Ceci, Williams, & Barnett, 2009; Ceci *et al*., 2014). In short, the argument is that males already exhibit better three-dimensional spatial-rotation ability by 3–4 months of age, and this spatial superiority grows over time to give them an advantage in mathematics (e.g., geometry) and spatial cognition, two key aptitudes involved in fields such as engineering, computer science, and physics. There have been over

100 analyses showing substantial male superiority in three-dimensional mental rotation, with effect sizes favoring men that are large, on the order of 0.5–1.0 standard deviations (Voyer, Boyer, & Bryden, 1995). The male superiority for spatial 3D rotation is found across the life span (in infants through the elderly) and across many nations (Ceci *et al.*, 2009).

There are three main reasons why we were led to reject this hypothesis as a major explanation of women's underrepresentation in math-intensive careers. First, the picture is more complicated than the infant studies suggest, with some failures to replicate and some studies finding no sex differences by 9 months of age. Generally, sex differences at this early age are also dependent on whether the mental-rotation task requires a rigid surface transformation or a nonrigid one (a shape that is rigid is one in which the distance and orientation of points within it remain unchanged when the shape is transformed or rotated; sex differences are often pronounced on such rigid surface rotations) and whether the task is speeded or not (see Ceci *et al.*, 2014 for review).

Thus, it is not a simple matter of males being better than females. Second, on average, girls and women do as well as boys and men in mathematics from the early grades through college; on average, females earn 0.1–0.2 grade points higher than males in math courses. In other words, there are few persuasive causal connections between early spatial ability and subsequent mathematical ability. If women comprise nearly half of the bachelor degrees in mathematics, and on average they earn better grades in mathematics classes throughout high school and college, then how can early spatial differences be responsible for their underrepresentation in mathematical fields? Thus, whatever native ability advantage males have in mathematics and spatial cognition, it does not seem to preclude females from achieving at high levels in mathematics.

However, the above evidence of sex differences in spatial and mathematical ability is based on *average* performance, not on stellar performance, which some might argue is needed to be successful in math and engineering fields. Specifically, although there are no sex differences in average math scores, males are overrepresented among the top 1% on math aptitude tests such as the SAT-M and GRE-Q (both by ratios of approximately 2 to 1). So, can this 2–1 asymmetry at the right tail of the math-ability distribution explain the shortage of women in math-intensive fields? Perhaps, to get accepted into doctoral programs in highly quantitative fields, there will be two male applicants admitted for every one female applicant admitted. Although this could contribute to women's shortage in math-intensive fields, we concluded that the 2:1 ratio among the top 1% of math scorers would predict many more women in these fields, *if* mathematics was the controlling reason for their shortage. Depending on the math-based field under analysis, women today occupy fewer than 16% of full professorships (and sometimes even fewer than 5%). Thus, if the dearth of women in these professions was the result of a 2:1 ratio in mathematics aptitude alone, then there should be at least one-third women in them, but fewer than half that percentage of women occupy top positions.

As a side note, there are many examples of cultural and ethnic reversals of male superiority among high math scorers. In the United States, for example, female Latino kindergartners outperform male Latino kindergartners, and across the globe, there are other instances in which females excel over males at the right tail of the math distribution (Ceci, Ginther, *et al.*, 2014; Ceci, Williams, *et al.*, 2009). This does not gainsay the very real overrepresentation of males among the top 1% or beyond (e.g., males outnumber females at the extreme right tail, i.e., the top 0.01%—1 in 10,000—*roughly 3.8:1*). But, it does argue that such sex differences are not carved in stone and that elsewhere females have achieved parity or superiority, suggesting that the sociocultural environment plays an important role in bringing latent talent to fruition.

Bias Against Women and Their Work-Products

If math and spatial advantages enjoyed by males cannot account for the relatively lower percentage of women engineers, physicists, computer scientists, economists, and mathematicians, then what factor can? One common argument is that it results from bias against women and their work-products, affecting interviewing and hiring and evaluations of lectures, manuscripts, and grant applications. This is a common claim in gender-equity reports and in the media, and we have documented many recent such claims (Ceci *et al.*, 2014). A frequent claim is that women are in short supply, because they have to be better than men to be interviewed and hired. In short, the claim of biases against women scientists and engineers by search committees that prefer to hire males over equally (or more) qualified females, by grant panels that downgrade proposals from women scientists, and by journal editors and reviewers who rate papers higher when a male name is on it, is pervasive. Consider a few of the many such claims, which we have catalogued elsewhere (Ceci *et al.*, 2014):

> “It is now recognized that (sex) biases functional many levels within science including funding, allocation, employment, publication, and general research directions”
>
> *(Lortie et al., 2007, p. 1247).*

> “These experimental findings suggest that, contrary to some assertions, gender discrimination in science is not a myth. Specifically, when presented with

identical applicants who differed only by their gender, science faculty members evaluated the male student as superior, were more likely to hire him, paid him more money, and offered him more career mentoring"

(Moss-Racusin, C. Commentary and Analysis from SPSP.org *September 21, 2012* http://spsptalks.wordpress.com/2012/09/21/are-science-faculty-biased).

"Research has pointed to (sex) bias in peer review and hiring. For example, 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"

(American Association of University Women: Hill, Corbett, & Rose, 2010, p. 24).

"Psychological research has shown that most people– even those who explicitly and sincerely avow egalitarian views– hold what have been described as implicit biases … There are countless situations in which such mechanisms are triggered: classroom situations, hiring committees, refereeing of papers for journals, distribution of departmental tasks (research, teaching, admin.) etc."

(Oct. 2, 2010 at http://www.newappsblog.com/2010/10/implicit-biases-1.html).

"Women and minorities must both deal with implicit bias, a problem that is well-documented in the social science literature … Donna Dean (President of the Association for Women in Science) describes the problem of implicit bias in these terms: 'People are most comfortable with people who think and look like themselves."

(Powell, K. (2007). Beyond the glass ceiling. Nature, 448, p. 99)

October 8, 2013 issue of *US News & World Report;* the headline reads*:*

STEM Roundup: Bias, Not Babies, Hamper Women in STEM (http://www.usnews.com/news/stem-solutions/articles/2013/10/08/stem-roundup-bias-not-babies-hamper-women-in-stem?s_cid=rss:stem-roundup-bias-not-babies-hamper-women-in-stem)

Another recent illustration of the bias claim can be seen in the *New York Times Sunday Magazine* article by Pollack, October 2013, who writes that the underrepresentation of women in math-intensive fields is due—at least in part—to male underestimations of women's competence and that this is why women are not hired for tenure-track jobs. Her essay is replete with such claims, for example, when she quotes a male mathematics professor at Yale about his explanation for the shortage of female math professors there*:*

"I guess I just haven't seen that many women whose work I'm excited about." (http://www.nytimes.com/2013/10/06/magazine/why-are-there-still-so-few-women-in-science.html)

An even more recent version of this claim appears in an article in the journal *Nature* and the myriad blogs that it spawned, for example,

> "In the past, fewer women worked outside the home and as that gradually shifted, there was hiring bias, which means historically women have had fewer science citations than men. That's simple numbers, just like fewer handicapped people and conservatives get citations in modern academia. But is that bias? The authors (in Nature) say it is."
>
> *(Science 2.0* http://www.science20.com/news_articles/are_journal_citations_biased_against_women-126192*)*

Given the ubiquity of such claims of bias in evaluating and hiring women, one might imagine that the evidentiary base of these claims is sound. On one level, it is—each of the above claims is supported by studies demonstrating that women or their work-products (e.g., papers, grants, lectures) are downgraded *vis-à-vis* comparable work-products of men. Over a hundred such studies exist, dating back nearly four decades. However, there is a disconnect between these studies and the source of women's current underrepresentation in math-intensive fields. None of these showings of bias can be causally tied to the current shortage of women in the math-intensive fields—the very fields where they are most underrepresented. We have reviewed the evidence for the claim that grant and journal reviewers are biased against women and found it lacking. We have also reviewed the evidence regarding biased hiring and have found it lacking as well—in fact, real-world hiring data show that actual hiring decisions in STEM fields favor women (Ceci *et al*., 2014). Taken as a whole, this large literature provides no support for the claim of bias against women by journal and grant reviewers or by search committees, notwithstanding assertions to the contrary. Our conclusion stated:

> "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 occasionally 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*"
>
> *(Ceci & Williams, 2011, p. 3157).*

Sex Differences in Career Interests

If neither female inferiority in mathematical aptitude nor bias against hiring female applicants or rating their work-products is the primary cause of the dearth of women in math-intensive fields, then what is? Part of the answer to this question begins long before women apply for tenure-track careers in science and engineering departments—even before they decide on their college major. The other part of the answer occurs much later and is rooted in the decision to become a mother. We begin with the first of these causes.

Sex differences in career interests and aspirations are evident long before college students declare their major. By early adolescence, surveys reveal that few girls aspire to be engineers, physicists, or computer scientists; in contrast, about a quarter of boys do aspire to working in these fields. Instead, girls profess to be interested in biology, law, and medicine, both human and animal. Generally, there is a so-called "people-thing" dimension along which males and female differ, with females tilting toward activities and careers that involve living things (nursing, social work, education, medicine, biology, animal science), whereas males are more likely to lean toward symbol manipulation and inanimate objects, hence engineering, computer science, and physics. This "people-thing" dimension has been amply demonstrated in surveys of over hundreds of thousands of people and suggests an important source of gendered differences in careers. In one meta-analysis of the people-versus-things dimension, Sue, Rounds, and Armstrong (2009) revealed large sex differences in vocational and educational choices; Lippa (2010) analyzed more than 200,000 people in 53 nations as part of a BBC Internet survey and reported a large effect size (1.40) in gendered occupations.

Adolescent girls appear less certain than boys that science has a positive societal influence, and they report being less certain that science can help solve environmental and social problems. They are also more likely to think scientists are "uncaring"; they are more unsure of their interest in STEM careers, and they have significantly greater interest in biology, whereas boys have greater interest in chemistry and physics (Bennett & Hogarth, 2009). Throughout high school, females maintain interests in medicine, biology, law, humanities, and social sciences, whereas males are more likely to prefer science and math careers. These early preferences are reflected in college majors, with roughly only 21% of physics majors being females, 22% of computer science majors being females, and 24% of civil engineers being females (electrical engineering and mechanical engineering each having around 13% females, and chemical engineering 17%).

None of these sex differences is immutable, however, and there have been dramatic increases in the percentage of females declaring math-intensive majors over the past 40 years; so, it is very possible that women's fraction of these majors will continue to increase. But, as far as the current dearth of women is concerned, these figures mimic the professed aspirations of boys and girls in adolescent and high school surveys and are therefore unsurprising. In fact, were it the case that women suddenly comprised half or more of engineering majors after claiming to be uninterested in the subject a few years earlier, *this* would be surprising. Of course, initial interest is not the entire story; for example, even among those females who aspire to science careers, more of them switch out of a science major than do their male counterparts (Ceci *et al*., 2014).

It is also the case that many more females have symmetrical ability patterns (high in both math *and* verbal ability) than males, who tend to be asymmetric, with high math ability coupled with unremarkable verbal ability. Research has shown that an asymmetric ability profile is associated with ability self-concepts that lead to entry into science fields. Wang, Eccles, and Kenny (2013) demonstrated that the decision to pursue a STEM career hinges on two things: (i) it presupposes a high level of math ability, and (ii) STEM entry is most likely to occur when high math ability is accompanied by relatively lower verbal ability, a condition more likely to be true of males. It is as if having only strong math ability leads one to think of herself or himself in terms, such as "I am good at math," whereas being strong at math and verbal leads to greater ambivalence about career goals. And, bear in mind that this finding occurs even when math ability is comparable between males and females.

Thus, sex differences in ability self-concepts and career interests are likely contributors to women's underrepresentation in math-intensive fields. Gendered preferences among adolescents and young adults lead to the shortage of women in fields that they rate as less desirable. A related gendered preference has to do with lifestyle choices made later in life, particularly, the choice to pursue motherhood (Williams & Ceci, 2012). Although among high school students sex differences in family formation are not pronounced, later in life the decision to have children becomes quite a significant factor in women's exit from tenure-track science careers. Women, and to a lesser extent men, increasingly express dissatisfaction with the work-obsessed lives of academics at research-intensive institutions, as opposed to teaching-intensive colleges. Surveys indicate that both women and men desire greater work–life balance. Women especially desire balance between the demands of a family and a job, something that surveys indicate men are somewhat less concerned about. A manifestation of this is that many more women PhDs than men PhDs *opt not to apply* for tenure-track positions or postdocs on finishing graduate school (Mason, Goulden, & Frasch, 2009; Williams & Ceci, 2012). The *mere plan to have children in the future* is sufficient to dissuade more women postdocs than men from pursuing fast-track research positions (Mason *et al.*, 2009).

In sum, in explaining women's current underrepresentation in math-intensive fields, we are left with two explanations that are compelling—sex differences in career interests and preferences, and sex differences in the choice to be a parent and in lifecourse planning related to parental roles. Men's superior ability in very high-level mathematics also probably contributes to women's choices to pursue other fields relative to men's choices to pursue math-based fields. And, outright bias and discrimination, while extremely important as a historical factor, has receded greatly in importance over the past four decades.

FUTURE DIRECTIONS

Research on women's underrepresentation in science is being conducted in numerous disciplines—psychology, economics, sociology, and beyond—and the body of literature grows daily. Our understandings of the critical factors in underrepresentation today must evolve quickly to keep pace with the growing body of knowledge on the topic. The most fruitful new analyses are likely to be the ones that disentangle the complexities that mark key decision points in women's lives—decisions about what subjects are interesting and whether to take math- and science-focused programming in middle and high school, decisions about college majors and auxiliary coursework, and later about potentially applying to graduate school in STEM fields, decisions about whether to apply for tenure-track academic jobs, or to follow a partner's career, or to delay children, or to have them earlier in life. We also need research on why women choose to leave the academy, and to what extent they are pushed out versus simply wanting another life with more time for children and nonwork pursuits. Our understandings would be informed by lifecourse analyses that remain open to the possibilities that discrimination so characteristic of older women's experiences has been greatly reduced in the lives of younger women, and that these younger women may face very different challenges today. The most informative future directions for research on the women in science debate will explore the challenges of choosing motherhood for STEM scientists, and hopefully will open a discussion of how these challenges can be softened so that women are not forced to leave a potentially fruitful 40-year career because of the needs of their children during a single 5-year span of time. In sum, the best tools for researchers interested in helping women maximize their well-being and success are surely an open mind about what exactly limits women today and an awareness of the huge corpus of high-quality, empirical work across many fields of inquiry that can inform the debate.

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