A comparative examination of research on why women are more underrepresented in some STEMM disciplines compared to others, with a particular focus on computer science, engineering, physics, mathematics, medicine, chemistry, and biology

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Summary

In this paper, we make two main arguments. First, the “gauntlet” metaphor of the experience of women in science is more accurate than passive constructions such as “pipelines” or “climates” and leads to a more productive discussion of interventions for change. Second, while some interventions and recruitment efforts have increased the representation of white women in science, representation of marginalized women scholars, including women of color, disabled women, LGBTQ women, and gender minorities, are not improving, and in some cases are getting worse. We suggest some broad cultural and structural issues that contribute to issues of gender representation in science, as well as give specific examples from scientific disciplines to understand how historical and locational contexts require fine-tuning of solutions.

Introduction

Even in science disciplines where women are overrepresented among undergraduate majors, women are less represented as one moves up the training and career ranks. Usually, such declines are characterized as caused by “the leaky pipeline” or “chilly climate” (Banerjee and Pawley, 2013; Blickenstaff, 2005; Green, et al., 2010; Pawley and Hoegh, 2011). Conceptualizing the science workplace as a leaky pipeline or chilly climate leads naturally to efforts to turn up the tap (increase recruitment), attempts to plug the holes or turn up the thermostat (creating family-friendly policies like maternal leave, lactation rooms, and tenure clock stoppages), or telling women to put on a sweater (teaching cultural competence or giving improved mentoring to women scientists that is aimed at enduring a hostile climate). These passive constructions depersonalize the causes of low representation and instead characterize them as issues of low interest, inadequate training, or simply bad policy. Why is it, then, that (1) with all our efforts to improve recruitment, many sciences have seen so little improvement in gender representation, and (2) universities with good policies do not always have more women in their ranks?

Analyses of the narratives of women in science suggest a very different metaphor for the conditions that hold women back, reduce their productivity and success, or force them to leave: a “gauntlet” (Pawley personal communication; Banerjee and Pawley, 2013; Metcalf, 2011; Pawley and Hoegh, 2011; Urry, 2015). Conceptualizing the science workplace as a gauntlet makes it clearer that the primary determinant to women’s success in science is that they face greater and more active hindrances than men. A gauntlet is a punishment where someone must run between rows of people who are hitting them with sticks. Across STEM, the people “hitting” women are their coworkers, their students, and their bosses, as well as patients, clients, and other people outside the workplace. The gauntlet metaphor is upsetting to some, as it makes obvious the direct acts that lead to women having a harder time being successful in science disciplines or staying in science. Passive metaphors are more comfortable because no one needs to define or visualize the bad actors. The gauntlet, as an active metaphor, highlights the need for a different set of recommendations aimed at stopping negative workplace behavior and resolving unequal applications of existing policy.

To further extend this metaphor, the “hits” need not be life-threatening or intentional. Rather, the hits may be mild, but they are punishing in their frequency. Experiences such as incivility and gender harassment, for example, can be constant reminders to women that they are not welcome in that environment (Cantalupo et al., 2018; Clancy et al., 2014; Cortina et al., 2001; Cortina et al., 2013; Kabat-Farr and Cortina, 2012; NAS, 2018; Nelson et al., 2017). Substantial research suggests implicit and explicit biases discourage women from entering science careers in the first place (Cheryan et al., 2015; Lehmann et al., 2006; Master et al., 2016) or force them to leave after beginning their careers (Hunt, 2016). These findings counter the gender essentialist belief that women are not interested in certain scientific disciplines (Smith and Pawley, 2011).

Many initiatives aimed at increasing women in science focus on encouraging girls to pursue interests in science. However, comparatively little effort has been aimed at remedying the factors that serve to push women out of science. These factors include a continuum of explicit and implicit biases, and structural and interpersonal interactions that impede or even sabotage women's progress (Grogan, 2018; Urry, 2015). They intersect with class privilege and racial discrimination, which means they disproportionately affect women of color and first-generation scholars. As a result, white women benefit disproportionately from programs aimed at increasing the number of women in science generally, while, conversely, the number of women of color in science faculty positions has declined (Armstrong and Jovanovic, 2015). Efforts aimed at recruiting and retaining women faculty are also less successful at the senior (e.g., associate or full professor) ranks (Aaronson et al., 2004) than at the junior (e.g., assistant professor).

For women from underrepresented groups including Native Americans, American Indians, black/African Americans, and Latinas, the intersectional nature of the gauntlet serves to prevent access and success in scientific careers (Armstrong and Jovanovic, 2015; Rios and Stewart, 2015). Further obstacles also exist for women with disabilities and for gender and sexual minorities; however, there are few data available to evaluate the representation of these groups (Armstrong and Jovanovic, 2015). Differences in how these factors differentially play out across scientific disciplines are due largely to organizational tolerance of exclusionary behaviors due to disciplinary culture, often in the name of scientific excellence and rigor. Variation in the culture and extent of male domination, and concomitant tolerance for expression of bias and harassment creates cultures that vary in their passive and active hostility toward women.

1. Common Dynamics across the Sciences

Masculine Context

There are long-standing cultural associations between masculinity and objectivity, which in turn underlie the associations of masculinity with science (Bejerano and Bartosh, 2015). These gendered messages of science are implicitly conveyed in cultural portrayals of science and science education. Thus, these patterns shape the social and educational environments in which children grow up, as well as structural patterns that occur in academic science. However, although science has overall associations with masculinity, different disciplines vary in the degree to which the masculinity context permeates the field. Male domination, and association with male-associated traits, including objectivity, rationality, and brilliance, tend to be more severely male-biased (Bejerano and Bartosh, 2015; Cheryan et al., 2015; Leslie et al., 2015; Master et al., 2016).

The masculine nature of science is transmitted as a form of a hidden curriculum that structures the practice of science, including education and research (Bejerano and Bartosh, 2015). Hidden curriculums are unstated ideas and norms that are implicitly transmitted and required for successfully mastery of a discipline (Anyon, 1980; Bejerano and Bartosh, 2015; Sambell and McDowell, 1998; Walton and Cohen, 2011). For example, gendered language in college syllabi often betrays gendered stereotypes (Bejerano and Bartosh, 2015). Furthermore, disparities in mentoring and inclusion/exclusion in peer networks often provide white, affluent, male students with information on unspoken expectations that other students are may not be informed about (Bejerano and Bartosh, 2015; Pawley and Hoegh, 2011; Sambell and McDowell, 1998; Walton and Cohen, 2011).

Critical Mass Paradox

Theories based on the concept of critical mass suggest that once women achieve a certain threshold of representation, their experiences in the discipline should improve (Etzkowitz et al., 1994; Kulis et al., 2002). However, there are mixed effects of how this plays out across the sciences. On one hand, women in higher female-ratioed groups have access to female mentors, as well as peer support from other women. The role of social support from peers is crucial to surviving negative experiences during periods of undergraduate and graduate training. For example, women in doctoral cohorts that contain other women are more likely to persist in finishing their degrees (Bostwick and Weinberg, 2018). Furthermore, women of color in the sciences benefit from social support to counter internalizing negative workplace experiences (Rodrigues et al., in review). However, the increasing numbers of women at the undergraduate and graduate levels cannot overturn cultural patterns that are enforced by those at the top of the hierarchy (Etzkowitz et al., 1994; Kulis et al., 2002). If those cultural values continue to perpetuate inequalities and drive women out as they attempt to climb to higher ranks, both the cultural status quo and disparities at higher levels will remain unchanged.

In fields that are male-dominated and stereotypically gendered as “male,” women succeed by modeling the behavior of the successful men who train them (Etzkowitz et al., 1994). Women in male-dominated environments are more likely to direct incivilities and harassment to junior women (Derks et al., 2011; Derks et al., 2016). This may be related to the gender distancing that occurs in male-dominated fields, where women who identify with interests and traits associated with the discipline identify less with stereotypically feminine traits (Charleston et al., 2014; Pronin et al., 2004). For example, undergraduate women who take many math classes and identify strongly with math distance themselves from stereotypically feminine qualities like wearing makeup or wanting to raise children (Pronin et al., 2004). As women internalize negative messages about stereotypically female traits, women who are interested in "masculine" disciplines disavow feminine stereotypes and, in turn, harshly judge other women for exhibiting those traits.

This dynamic also occurs across racial lines, where racial minorities distance themselves from other minorities in order to demonstrate alliance with the dominant group (Charleston et al., 2014; Derks and Laar, 2015). This may especially contribute to the marginalization of women of color. In some cases, female supervisors in male-dominated environments may be harsh on female trainees because they believe trainees must "toughen up" to be competitive in the field (Etzkowitz et al., 1994). Even when women recognize these dynamics and consciously try to change the dominant culture, they may struggle to make those changes without sacrificing professional goals or the appearance of competence in their peers' judgments.

Even in female-dominated sciences, men have advantages that secure more prestige and higher-ranking positions. For example, primatology is an interdisciplinary science in which women have been well represented since the 1970s (Addessi et al., 2012; Fedigan, 1994; Isbell et al., 2012). However, at professional meetings, men give significantly more talks, whereas women present significantly more posters (Isbell et al., 2012). Furthermore, speakers for symposia organized by all-male teams are predominantly male (71.2 percent), compared to those organized by mixed-gender (41.5 percent male) or all-female teams (36.5 percent male). Like other sciences, primatology has a "glass ceiling" effect where women are over-represented as students and remain well-represented at lower numbers as assistant professors, but are underrepresented at the full-professor level (Addessi et al., 2012). This is despite a multi-decade history as female-dominant, and the fact that male and female professors have comparable H-indexes (Addessi et al., 2012). This example highlights how equal representation, with even heavily unbalanced over-representation at the student level, cannot overcome structural barriers. Put simply, pushing more women into the "pipeline" does not achieve gender parity.

Cascading Effect of Systematic Gender Imbalances

Women experience implicit bias and structural barriers at every level of evaluation (Grogan, 2018; Urry, 2015), and these barriers are intensified for women of color. Biases in evaluation at each stage of scientific career advancement create moments of selective pressure at each juncture, where women must perform better for equal consideration. Women in science experience disparities in recruitment, funding, allocation of resources, and mentoring (Grogan, 2018; Hechtman et al., 2018; Moss-Racusin et al., 2012; Pohlhaus et al., 2011; Urry, 2015; Witteman et al., 2018). These barriers occur at key career junctures, from recruitment into lab management positions intended for promising future graduate students, to consideration for graduate admissions, consideration for postdoctoral positions, hiring in tenure-track positions, and promotion (Bronstein and Farnsworth, 1998; MacNell et al., 2015; Milkman et al., 2015; Moss-Racusin et al., 2012; Settles et al., 2006; Urry, 2015).

Small, early biases have cumulative effects leading to outsized disparities at later career stages. For example, a promising undergraduate who secures a prestigious research experience may then be hired as a lab manager, get into an elite university for graduate study, receive a National Science Foundation graduate fellowship, and consequently receive mentoring from a high-ranking professor who provides publication opportunities. When biases result in male students being identified as more promising for initial research experiences, the effect of that bias will reverberate, continuing to provide additional opportunities for career advancement. Men are more likely to be evaluated in ways that lead to opportunities for better pay and mentorship (Moss-Racusin et al., 2012). Additionally, these biases especially favor white men over men or women of color (Milkman et al., 2015).

In academic positions within science, women are more likely to be appointed in teaching-focused positions, where they have less access to funding and resources and will not train graduate students (Hermanowicz, 2012; NASEM, 2018). Disparities in teaching evaluations put women, particularly women of color, in a risker position when going up for tenure at teaching-centered institutions (Jones et al., 2015; Pittman, 2010; Reid, 2010). Women are less likely to receive authorship credit, are cited less, and experience harsher peer review (Bendels et al., 2018; Chawla, 2018; Murray et al., 2018; West et al., 2013). Women are less represented as first authors, last authors, and reviewers (Chawla, 2018; Lariviere et al., 2013; Murray et al., 2018). Furthermore, all-male reviewing teams are more likely to reject papers from women (Chawla, 2018; Murray et al., 2018). Women are also less frequently invited to be colloquium speakers than men, particularly at prestigious universities (Nittrouer et al., 2017).

There are also gender disparities in grant funding (Pohlhaus et al., 2011; Witteman et al., 2018). For example, women apply for National Institutes of Health funding at lower rates, and are less successful at receiving renewed funds (Pohlhaus et al., 2011). For other funding sources, women's research is evaluated favorably, but they are judged more harshly when their personal accomplishments as a principal investigator are evaluated (Witteman et al., 2018), and as a result, men continue to be funded at higher rates.

Even among fields where women are well or over-represented at lower levels, they still struggle to achieve representation at higher ranks (Addessi et al., 2012; Carnes et al., 2008; Isbell et al., 2012; Sheltzer and Smith, 2014). One reason is that there are gendered divisions of labor within academia. Women tend to shoulder the burden of academic "housework," including teaching, mentoring, and service (Armstrong and Jovanovic, 2015; Hermanowicz, 2012; Kulis et al., 2002; Madge and Bee, 1999; Urry, 2015). Particularly for white women in male-dominated fields and minority women in all fields, there is a "cultural taxation" in which women must perform additional service work related to their identity (Armstrong and Jovanovic, 2015). Furthermore, women are often marginalized in low-status jobs such as non-tenure-track positions or unstable research-associated positions dependent on soft money (Kulis et al., 2002). Across a variety of fields, as women increase in representation, status and pay decrease (Kulis et al., 2002; Reskin, 1988). Furthermore, even as women rise to higher ranks, they continue to perpetuate culturally engrained biases. Women are just as likely as men to negatively evaluate female candidates, and the presence of high proportions of white women and minorities does not decrease the perpetuation of biases in evaluating prospective students (Milkman et al., 2015; Moss-Racusin et al., 2012).

Finally, women disproportionately deal with the impact of the two-body problem, in which partners find it challenging to find employment at the same institution or city, as well as the impact of inadequate maternal/paternal leave and childcare (Urry, 2015). While some studies/researchers frame the exit of women from academic science as a choice based on prioritizing relationships and/or motherhood (Ceci and Williams, 2011), these "choices" are often forced by gender inequities in cultural expectations combined with bias against women who have children, or may even potentially have children in the future (Wolfinger et al., 2008).

Double Bind Experienced by Women of Color

For women of color, the experiences of gender discrimination are compounded by racial and ethnic discrimination, which contribute to a "double bind" in which women of color experience increased bias at key career junctures and often hostile environments (Berdahl and Moore, 2006; Berenstain, 2016; Clancy et al., 2017; Kabat-Farr and Cortina, 2012; Ko et al., 2014; Ko et al., 2013; Milkman et al., 2015; Ong et al., 2011; Settles et al., 2006). For example, women of color experience incivilities, defined as subtle forms of rudeness and social exclusion of ambiguous intent, in greater numbers than white women, men of color, or white men (Cortina et al., 2013; Kabat-Farr and Cortina, 2012). In addition to incivilities and sexual harassment, women of color also experience racial harassment and intensified forms of sexual harassment (Berdahl and Moore, 2006; Buchanan and Fitzgerald, 2008).

Our laboratory explored the ways in which women of color faculty, who are often socially isolated in their departments, navigate incivilities. We conducted focus groups to examine the frequency of negative workplace experiences among women of color science faculty and determine whether women were able to access social support (Rodrigues et al., in review). Women in all six focus groups reported incivilities, sexual harassment, and racial harassment (Rodrigues et al., in review). Incivilities were the most frequent, and their ambiguous nature left many respondents constantly questioning why they were being professionally sabotaged, neglected, excluded, or otherwise mistreated (Rodrigues et al., in review). Non-tenure-track faculty experienced negative experiences that were substantially worse than tenure-track and tenured faculty.

Our most compelling findings related to the ways in which science faculty who are women of color find or are let down by purported social support. Responses from white colleagues were especially complicated. Women of color faculty in our sample reported positive experiences including white colleagues intervening during acts of incivility or racial harassment (Rodrigues et al, in review). However, more often, participants reported negative experiences with white allyship that we consider "collegial gaslighting," when someone denies the external realities that one is experiencing or insists that one cannot trust one's own perception (Berenstain, 2016; Roberts and Carter Andrews, 2013). In an academic science context, collegial gaslighting refers to often well-meaning attempts by purported allies to minimize or deny women of color's experiences of incivility and harassment (Rodrigues et al., in review). Additionally, participants reported that poorly planned initiatives around diversity and inclusion also contributed to collegial gaslighting, as participants were pressured into maintaining the appearance of inclusion without experiencing genuine inclusion—for example, by attending Black History Month events that participants found problematic. Some of these negative experiences should point a clear path forward for white faculty who want to be allies. Diversity efforts that do not center the experiences and wishes of the underrepresented and underserved members of their departments are not effective ways to improve the climate.

However, true social support, particularly from other women of color, played an important role in helping participants cope with and contextualize negative workplace experiences. Many participants reported a sense of attributional ambiguity, in which they were unsure whether the causes of negative treatment were related to gender, race, or their own worth as a scientist (Rodrigues et al., in review). The uncertainty surrounding these experiences caused participants to question whether it was something they had done or the quality of their work. We found that social support from other women of color was crucial to externalize these experiences (Rodrigues et al., in review). These findings point an additional path forward that includes cohort hiring of women of color in order to encourage social support among people with similar lived experiences and as an inoculation against sometimes hostile, sometimes well-meaning but misguided white faculty.

2. The Cultural Context of STEM

In the sciences, a number of factors hamper gender and racial equality, including positional hierarchy, an emphasis on pedigree, principal investigators' control over funding, and a firm belief that all processes are inherently meritocratic. Elite universities like to curate collections of scientists, which trickles down into departmental cultures and expectations in peer and aspiring universities. Obtaining federal funding begets more federal funding, which creates a widening gap between established scientists and those forging new paths (Bol et al., 2018; Squazzoni and Gandelli, 2012). Together, these phenomena produce a culture where successful scientists often believe that their own career successes, and those of colleagues, are justified and that rank order is part of the natural order. In time this can create a permissive environment of hostile behavior, particularly toward those who are low ranking or viewed as "uppity."

Positional hierarchy refers to conditions where hierarchy is not justified by any particular quality but instead by the length of time someone has held a position and/or title (NASEM, 2018). Intellectually, most scientists know that under some conditions, a full professor may have less expertise than a more junior scholar on a given topic; however, senior scholars enjoy a kind of runaway selection that continues to reward them in funding see the distribution of success rates in the National Institutes of Health: Charette et al., 2016) and control over departmental culture or direction. Many academics want to wait until tenure to say or do certain things, when academic freedom will purportedly protect them. But academic freedom protects white men upholding the dominant cultural paradigm while not adequately protecting women of color, white women, men of color, or even white men seeking to overturn it (Salaita, 2015; Schmidt, 2018).

Control of principal investigators over funding forces trainees to endure difficult or even deeply unethical working conditions in order to keep their jobs, get their degrees, and get the letters of recommendation that make or break their next career stages. Many trainee scientists are paid directly out of their advisor’s grants rather than by their institution, which puts the advisor in full control of that scientist’s success or failure. Visa holders are especially vulnerable to abuse: international trainees are often paid far less than American trainees and are forced to work longer hours or endure quid pro quo harassment under the threat of having their visa revoked (Cantwell and Lee, 2010; Hayter and Parker, 2018; Shinbrot, 1999). Women of color, white women, and other trainees who may not fit their advisor’s conception of a scientist may get less attention and fewer resources, even while still being completely bound to their advisor’s good will. LGBTQ+ scientists may feel the need to remain closeted if they are unsure of their advisor’s perspective on their rights and personhood (Atherton et al., 2016).

The meritocracy myth is another factor influencing how different people experience science cultures. While the American belief in meritocracy—that people have success based on their hard work and ability rather than their privilege, luck, or other factors—is widespread, it has a particular stranglehold on the sciences. We believe the best scientists produce the best trainees and produce the best science and that excellent scholars always receive their bona fides (NASEM, 2018). We rarely acknowledge the additional burdens faced by scientists who are underrepresented and underserved in these fields. These burdens range from a lack of social support, to fewer or further bathrooms, to the pressure to resist stereotype threat, to enduring repeated microaggressions, incivilities, harassment, or assault (Atherton et al., 2016; Barthelemy et al., 2015; Cantalupo et al., 2018; Clancy et al., 2017; Clancy et al., 2014; Pronin et al., 2004; Rodrigues et al., in review; Steele and Aronson, 1995). Marginalized scientists must constantly decide whether to code-switch to adopt the language and behavior of the dominant group while at work or assert their own cultural markers and lived experiences.

Cultural Differences across the Sciences

While bias, discrimination, and harassment exist across all STEM disciplines (and, we would contend, across all American workplaces), the form that these phenomena take varies with the history, culture, and context of the space in which the work is being done. For instance, in disciplines where much of the work takes place outside of traditional professional spaces—observatories late at night, remote field sites that require extensive hiking or camping, laboratory experiments that require additional work on the weekends—incivilities, harassment, or assault can be more common (Clancy et al., 2014; Nelson et al., 2017). Across all disciplines, professional conferences can be places of heightened stress and risk for hostile behavior for underrepresented groups because of the introduction of informal receptions, late night alcohol, and the types of hierarchical posturing that lead to exclusionary behavior (Clancy et al., 2017; NASEM, 2018).

The culture of these disciplines also matters: For instance in physics, astrophysics, and planetary science, it is more common for invited speakers to be interrupted during their talks, whereas in biology this is a rare phenomenon (NASEM, 2018). Biology and physics also have very different histories. As sociologist of science Joseph Hermanowicz writes, “physicists possess a recognizable genealogy of immortals—the likes of Kepler, Newton, and Einstein—who promote a sense of scientific heroism and define a “model” career for those who follow” (2009: p. 42). In biology, those heroes and history are quite different: Darwin, Mendel, Goodall, and Carson. The history of the field and mechanisms of discovery lead to very different stories of what it means to be a scientist in these disciplines.

The downstream effect of these cultural histories is that success in physics is presumed to hinge on innate brilliance, whereas in biology success hinges on effort (Leslie et al., 2015). In disciplines where successful academics are expected to have “raw, innate talent”—a trait believed to be held by men more than women—women are less well represented (Leslie et al., 2015). Stereotype threats around intelligence and brilliance may have a stronger hold in physical science disciplines, creating a culture of “nerdbros” that prizes confrontation, elitism, and exclusionary behavior. But the idea that there are some people in science who are savants, who are identified early and naturally make their way to the highest ranks, persists across many disciplines. The culture of brilliance may lead to incivilities that undercut, deride, or display contempt for others. Incivilities in general are perpetrated more against women of color and white women than other groups (Cortina et al., 2013; Kabat-Farr and Cortina, 2012). The negative experiences that marginalized individuals encounter are likely related to social exclusion, where subtle incivilities serve as constant reminders that they are not welcome.

The culture of effort and “hustle” is not necessarily healthier than one that relies on assumed raw talent. Cultures of hustle encourage a work-life blurring, as well as the transgressing of other boundaries. There are engineering and biology labs that operate 24 hours a day, and paleontology and archaeology field sites that blend dig time, processing time, and party time (Clancy et al., 2014; NASEM, 2018; Nelson et al., 2017). In the hustle culture, stereotypes around women who nurture, as well as actual expectations they may have with elder or child care, may make it harder for them to engage fully in the trope of the scientist so fully engaged in his work he forgets to eat or call his wife. And when professional boundaries are blurred, misbehavior like harassment and assault can be intentionally perpetrated in the name of collegiality or over-friendliness (NASEM, 2018; Wurth, 2018).

3. Representation of Women across the Sciences

Across the sciences, there is variation in the levels of representation by white women and women of color. For example, even though the percentage of female engineers doubled from 2001 to 2010, the percentage in 2010 was still extremely low at 16 percent, and slightly declined by 2015 (Armstrong and Jovanovic, 2015; NSF, 2002, 2011, 2017). Similarly, even though women’s representation in the physical sciences improved during this time period, women still accounted for only 22 percent of these disciplines in 2010 (Armstrong and Jovanovic, 2015; NSF, 2011). Such variation may be due to disciplinary cultures that vary in tolerance of overtly sexist and/or racist beliefs about innate intelligence and aptitude, as well as cultural tolerance for harassment and incivility. Here, we explore some of the dynamics in each discipline.

Computer Science

Computer science is a field with an extremely low representation of women (Master et al., 2016). In this field, only 20 percent of bachelor's degrees are awarded to women (NSF, 2017). Therefore, the barriers to women in computer science are frequently characterized as a "pipeline" problem. This is part of a widespread perception that girls and women are simply uninterested in computing and programming (Fisher et al., 1997). The reality, however, is more complicated. Despite frequent speculation that girls and women are not interested in computing, research on cultural attitudes suggests that adolescent girls are bombarded with stereotypes that computer science is a masculine field (Fisher et al, 1997; Lagesen, 2007; Master et al., 2016; Rasmussen and Hipnes, 1991). Both girls and boys receive the message that computer science is a field ideal for "geeks" who are socially awkward, isolated, male, and brilliant, and even have physical characteristics like pale skin and glasses (Beyer, 2014; Cheryan et al., 2015; Master et al., 2016; Rasmussen and Hipnes, 1991).

At the high school level, gender imbalances among students taking computer science classes leads to imbalances at the undergraduate level. These imbalances were an issue in the 1990s but continue to persist through the 2010s (Fisher et al., 1997; Master et al., 2016). Although stereotypical attitudes contributed to girls' perception that they do not belong, interventions to alter classroom environments can successfully counter conventional stereotypes (Master et al., 2016), suggesting that interventions at the high school level may be valuable in increasing the numbers of women who are interested in and prepared for computer science courses at the undergraduate level. However, the male-dominated culture at the undergraduate level may still push women out, as they are implicitly or explicitly told that they do not belong and experience sexual harassment (Fisher et al., 1997).

Several programs have focused on increasing the representation of women in computer science. These include programs focused on changing the masculine stereotypes of the discipline, changing disciplinary content, altering the educational environment to be more inclusive and less hostile (Fisher et al., 1997; Lagesen, 2007; Roberts et al., 2002). Despite the focus on changing stereotypes, some aspects of the stereotype, particularly the "geeky" attributes, may be a draw to women in and of themselves (Cheryan et al., 2015).

At the transition from undergraduate to graduate programs, retention rates for white women are high. In 2007, the percentages of white women awarded Ph.D.s (22.9 percent) was higher than the percentage awarded bachelor's degrees (17.4 percent) (Ong, 2011). However, the numbers for women of color, particularly underrepresented minorities, are extremely low. For example, like white women, the representation of Asian/Pacific Islander women was slightly increased at the Ph.D. level, comprising 2.5 percent percent of Ph.D.s awarded compared to 1.6 percent of bachelor's degrees awarded (Ong, 2011). Nonetheless, they were numerically few (17 women), and overall representation was much lower than the percentages of Asian/Pacific Islander men awarded bachelor degrees (6.8 percent) and Ph.D.s (10.5 percent) (Ong, 2011). Similarly, there were very few (14) members of underrepresented female minorities.

Because the problem in computer science is frequently framed by the leaky pipeline concept, only a few studies exist that allow us to examine broader cultural problems. Women of color in computer science experience isolation, where they are further marginalized beyond what white women experience (Charleston et al., 2014; Ong, 2011). Women of color, particularly black women, are challenged by their peers regarding their academic competence and credentials (Charleston et al., 2014; Ong et al., 2011). Furthermore, black women in computer science are marginalized by both white women and black men who prioritize gaining acceptance from the white men who hold cultural capital (Charleston et al., 2014).

At Carnegie Mellon University, directed efforts to recruit women resulted in an increase of representation from 7 percent to 42 percent over 15 years from 1995 to 2000 (Fisher et al., 1997). Changing admission criteria to avoid privileging extensive computer science experience at the high school level was effective. Overall, efforts shown to be successful at improving women's representation in computer science are direct recruitment focused on admitting higher numbers of women, bridge programs between high school and undergraduate studies, and inclusive policies (Fisher et al., 1997; Lagesen, 2007).

Engineering

In 2017, men earned 79 percent of the bachelor's degrees in engineering (APS, 2018). Like computer science, engineering is characterized by stereotypes associated with masculinity and geeky, antisocial tendencies (Cheryan et al., 2015). The low representation of women, context of masculinity, and stereotypical expectations all perpetuate an atmosphere that is hostile to women (Cheryan et al., 2015; Hunt, 2016). Furthermore, compared to other science disciplines, engineering has been characterized as particularly resistant to diversity and inclusion efforts (Burack and Franks, 2004).

The first point of departure in gender disparities in engineering is early socialization. In interviews, men are more likely to report early experiences with building and taking apart toys, whereas women are more likely to refer to role models who specifically encouraged them to pursue engineering, as well as targeted opportunities such as science camps and middle-school competitions (Chanderbhan-Forde et al., 2012). Those role models often included family members who were engineers who provided access to cultural capital the female students would otherwise lack. At the high school level, stereotypical expectations play a role in deterring women from gaining the necessary prerequisite coursework, and girls generally receive less encouragement to apply to undergraduate programs in engineering (Cheryan et al., 2015; Hunt, 2016).

At the undergraduate level, the masculine context and social exclusion create barriers. Female undergraduates pursuing engineering degrees receive less mentoring than male classmates and have few female role models to look up to (Chanderbhan-Forde et al., 2012). Although male engineering students also reported a dearth of mentoring, they were able to seek mentoring from upperclassmen, whereas female students relied on family members who were engineers or early mentors from high school programs. This suggests that women are only likely to enter or succeed within engineering if they have privileged backgrounds that give them access to mentoring.

Women have low representation as engineering faculty and professionals (Bejerano and Bartosh, 2015). In the same positions as men, female engineers make less money, receive less support for their research and ideas, and have fewer opportunities for advancement (Bejerano and Bartosh, 2015; Hunt, 2016; Xu, 2008). Compared to other fields, engineers are more likely to be employed in the field they were trained in; however, this is accompanied by high rates of gender disparity in leaving the field (Fouad et al, 2017; Hewlett 2008; Hunt 2016). Women who leave engineering careers cite three major factors: 1) gender disparities in pay in conjunction with difficult working conditions, 2) dissatisfaction with the underutilization of their experience and skills, and 3) lack of recognition or advancement opportunities (Fouad et al, 2017). The gender disparities in pay and advancement opportunities point to patterns of underlying structural discrimination in hiring and promotion (Hunt, 2016).

For women of color in engineering, the experience of marginalization is intensified (Chanderbhan-Forde et al., 2012; Foor et al., 2007; Ong et al., 2011; Tate et al., 2005). White women in engineering have fewer role models, mentors, and sources of social support than men, and this experience is drastically intensified for women of color. For black female students, there are few white female or black male faculty to look up to, much less black female faculty (Chanderbhan-Forde et al., 2012). Like black women in computer science, black women in engineering are likely to experience marginalization from both white female and black male peers (Charleston et al., 2014). Multiple minority status results in barriers in access to prerequisite education in high school as well as messages of social exclusion at the undergraduate and graduate levels (Chanderbhan-Forde et al., 2012; Foor et al., 2007; Ong et al., 2011). Minority women, particularly black and Latina women, are told explicitly or implicitly that they do not belong (Foor et al., 2007). Because faculty and peers may be unwelcoming, minority women often seek social support from sources outside their discipline and create separate social and academic peer groups (Cross et al., 2017; Mendenhall et al., 2018; Ong, 2011; Tate et al., 2005).

Physics

Physics has a strongly male-dominated environment, with many of the preconceptions of aptitude and brilliance that occur in other male-dominated sciences (Leslie et al., 2015). The number of women who received undergraduate degrees in physics peaked at 23 percent in 2002 and slightly declined to 19 to 21 percent in 2017 (APS, 2018). Thus, overall representation of women in physics is comparable to computer science and engineering (Kost-Smith et al., 2010). However, within related branches of the physical sciences, there is variation in the representation of women. For example, astronomy has twice as many women as other domains of physics (Urry, 2015).

Like computer science and engineering, enrollment in undergraduate physics programs and preparation for these programs reflect high school experiences. Male students enter introductory college physics courses with better preparation from high school physics classes (Hazari et al., 2006; Kost-Smith et al., 2010), despite that the female students have higher high school grade point averages than their male counterparts, and equal math preparation. This may be due to girls being discouraged from taking physics courses, or teachers directing their pedagogy toward male students.

Female undergraduates experience the same challenges as computer science and engineering undergraduates in finding mentors, role models, and peer support. A recent survey indicated that three-quarters of female physics majors experience sexual harassment, the majority of which is gender harassment perpetrated by their peers (Aycock et al., in revision). Women in physics graduate programs experience frequent microaggressions in which they are treated negatively compared to male graduate students, receive demeaning comments from both peers and faculty, and have their experiences and concerns dismissed (Barthelemy et al., 2016; Barthelemy et al., 2015). These experiences have both racial and gender components for women of color (Clancy et al., 2017; Johnson et al., 2017; Ko et al., 2014). In a survey of women in astronomy and planetary science (fields often considered subdisciplines of physics), 40 percent of women of color felt unsafe in their workplace environments, and both white women and women of color skipped professional events due to safety concerns (Clancy et al., 2017).

Chemistry

Chemistry is a discipline that has gender parity at the undergraduate level (Grunert and Bodner, 2011). For example, from 2000 to 2017, the proportion of women receiving undergraduate degrees in chemistry fluctuated between 48 percent and 52 percent (APS, 2018). Yet, like other sciences, the proportion of women declines at subsequent professional stages. The percentages of women obtaining master’s degrees and entering doctoral degree programs are far lower: In 2008 women received only 36.1 percent of chemistry doctorates, received 23.6 percent of postdoctoral fellowships, and comprised 18 percent of faculty applicants to positions in research-intensive institutions (Grunert and Bodner, 2011; NSF, 2011). In a survey of British doctoral students in chemistry, female students reported more issues with lack of mentoring and social marginalization than did male students (Newsome, 2008). Furthermore, women had issues with perceiving their research groups’ culture as inhospitable and often “macho” (Newsome, 2008). They also raised concerns about the isolating nature of their doctoral study and warnings they received that they had to sacrifice relationships and family in order to remain competitive in the postdoctoral and academic job markets.

Many women who make it to academic positions in chemistry find them unwelcoming (Green et al., 2010). Typically, men have higher salaries, are given better or larger research space, and are more likely to be promoted (Green et al., 2010). Men also receive greater recognition from the university, are more respected by students, and have an easier time gaining administrative assistance. Conversely, women are more likely to have higher teaching and service loads (Green et al., 2010). Women also believed that the barriers they experience were barriers to recruiting and hiring other women faculty and that there was overt opposition to hiring female faculty.

Mathematics

Mathematics is a discipline where aptitude is assumed to be due to innate brilliance and compounded by culturally engrained stereotypes (Cvencek et al., 2011; Leslie et al., 2015; Master et al., 2016). By the second grade, children form implicit and explicit associations between boys and math, and girls are less likely to state explicitly that they like math (Cvencek et al., 2011). Even for girls and women who excel at math, negative stereotypes hinder their mathematical performance. Stereotype threat is when awareness of a negative stereotype about an individual's identity leads to anxieties about confirming that stereotype (Spencer et al., 1999; Steele and Aronson, 1995). Middle-school girls who are told that they are taking a test that measure mathematical skills underperform on those tests when alone or in a mixed-gender group, but do not underperform in a same-gender group (Huguet, 2007). The impact of gender socialization and stereotypical association persist through high school and undergraduate studies. However, for Asian-American girls, there are competing stereotypical pressures: On the one hand, stereotypes associate female identity with poor mathematical aptitude, and on the other, stereotypes associate Asian identity with excelling at math (Ambady et al., 2001).

Early studies indicated that gender differences in math performance emerged in high school, but that gap has now closed (Hyde et al., 2008; Hyde et al., 1990a; Hyde et al., 1990b). Because girls and boys are similarly prepared by high school math courses, undergraduate women are well prepared for mathematics curriculum at the college level (Herzig, 2004). After degrees to women majoring in mathematics rose to a high of 48 percent in 1999-2000, they steadily declined to 41 percent in 2017 (APS, 2018).

The number of women in mathematics declines at the graduate level. For example, in 1996, 46 percent of bachelor's degrees in mathematics were awarded to women, yet women comprised only 33 percent of entering graduate students (Herzig, 2004). By 2002, the proportion of women hired into tenure-track mathematics positions was only 22 percent, indicating steep drop-offs between receiving undergraduate degrees and entering graduate school, and between receiving a doctoral degree and being hired into a tenure-track position. Furthermore, representation of black, Latina, and Native American women among doctoral recipients are extremely low. As in other fields, women leave mathematics at the doctoral and post-doctoral levels due to isolation and a lack of mentoring in their graduate experiences (Herzig, 2002; Herzig, 2004). Those who stay in mathematics are more likely to access cultural capital and mentoring networks due to family members in mathematics or involvement in undergraduate research experiences (Herzig, 2002). Negative experiences from faculty, such as exclusion from social networks and gendered harassment, also play a role in pushing women out (Herzig, 2004).

Medicine

There is near gender parity in medical school applicants, admissions, and graduates. However, female representation has slightly fallen in recent years (AAMC, 2016), and there are gender imbalances in specialization. Generally, women are well represented in specialties that involve women or children and are associated with nurturing, whereas men are better represented in specialties that require technical specialization (Carnes et al., 2008). As in many scientific disciplines, women are pushed out at higher ranks. For example, in 2015, women comprised 51 percent of M.D. instructors, but their representation declined at the assistant professor level (43 percent), associate professor level (33 percent), and full professor level (20 percent) (AAMC, 2016). Furthermore, there is a gender gap in medical publications, with women having low proportions of first authorships (29.3 percent) and senior authorships (19.3 percent) (Jagsi et al., 2006). Women in academic medicine receive less institutional funding and administrative support compared to male colleagues (Carr et al., 2003). One-third of women in academic medicine experience gender harassment, and many report that discrimination hinders their careers (Foster et al., 2000).

Of the disciplines examined in the recent National Academy of Sciences report *Sexual Harassment of Women: Climate, Culture, and Consequences*—engineering, the sciences, and the non-sciences—medical students had the highest rates of sexual harassment (NASEM, 2018). The hierarchical and hostile work environments in many academic medicine centers leads to greater bullying, intimidation, and harassment from patients, peers, and superiors. Harassment is a particular concern in medicine because it takes place in “environments with little structure or accountability for the faculty member, and a decreased ability for students to leave without professional repercussions” (NASEM, 2018, p. 55).

The hierarchical and hostile training landscape for doctors introduces considerable bias, which is harmful to both patients and the doctors themselves. Hostility and incivility have adverse effects on medical teams’ efficacy in diagnosis and treatment, and may have an even larger effect than sleep deprivation (Riskin et al., 2015). Biases regarding weight, gender, race, and other factors leads to missed diagnoses, delayed treatments, and poorer outcomes for many patients (Haider et al., 2015; Hoffman and Tarzian, 2001; Hoffman et al., 2016; Phelan et al., 2015; Suite et al., 2007; Trawalter et al., 2012). Racial and gender disparities in health are typically a result of psychosocial stress rather than inherent differences between groups, and patients’ knowledge that they will receive less attention or be taken less seriously are considerable stressors (Dressler et al., 2005; Geronimus et al., 2006; Gravlee, 2009; Suite et al., 2007). The ways in which these hierarchical and discriminatory practices are baked into the treatment landscape likely also have consequences for doctors who hold these identities.

Biology

Biology is one of the sciences in which women are not underrepresented. The percentage of women earning bachelor’s degrees in biology peaked at 62 percent from 2003 to 2006 (APS, 2018), and since then it has held steady, fluctuating between 59 percent and 61 percent between 2007 and 2017. Despite women’s representation at the undergraduate level, there are declines at later stages similar to those seen in other sciences (Addessi et al., 2012; Crangle, 2009; Ledin et al., 2007; Nüsslein-Volhard, 2008). Fewer stereotypes exist to hold women back from choosing to go into biology; however once there, they too face a gauntlet that undermines their success and increases their desire to leave.

In 2014, the SAFE team published its first findings on sexual harassment in the field sciences, most of which are biological sciences (Clancy et al., 2014). The team found that most women observed sexual harassment, a large number were sexually harassed themselves, and a significant minority were sexually assaulted while conducting fieldwork. In this sample, when women were harassed, the perpetrator was more likely to be senior to them in the workplace hierarchy; in contrast, when men were harassed the perpetrator was more likely to be a peer. Few respondents reported field experiences where there was a clear reporting mechanism for sexual harassment, and of the hundreds who shared that they experienced sexual harassment, only a handful reported the harassment, and only seven were satisfied with the outcome of that report. In 2017, the SAFE team published a follow-up to its original paper, this time of 26 interviews with field scientists (Nelson et al., 2017). It showed that the culture of the field sciences is one of unclear boundaries, few sanctions for bad behavior, and unequal access to resources for women. Many respondents shared that "what happens in the field stays in the field," and many were implicitly or explicitly told that they could not share what happened at their field sites. Respondents who reported harassment, spurned advances, or otherwise fought back in their harassing environment faced significant personal and professional consequences, from sabotage of their research to post-traumatic stress symptoms that impaired the write-up of their field research.

Women in biology also face substantial hiring disparities. At the trainee level, elite male faculty hire fewer women graduate students and postdocs; such a disparity is not found among elite female faculty (Sheltzer and Smith, 2014). Women are also hired at the faculty level less frequently at prestigious institutions, and instead funneled into less prestigious, more teaching-focused positions (Sheltzer and Smith, 2014). These findings point to lost opportunities for advancement for women in biology across the career stages.

4. Conclusion: We Need to Change Scientific Culture

These findings highlight widespread cultural challenges to implementing policies to improve representation of women across the sciences. First, across scientific disciplines, there are widespread examples of implicit and explicit bias that hinder women from advancing through their careers. These obstacles occur at every stage of scientific training and career advancement. Women are often pushed out entirely or stalled in positions of lower rank and prestige than those of male colleagues. The fact that these patterns exist across all sciences, including disciplines that have large numbers of women entering those fields, points to a systematic problem that cannot be solved by recruiting more women. Rather, we need to target efforts at recognizing and accounting for bias in evaluation, improving workplace climates, providing tools to prevent and disrupt incivility, and providing effective sanctions for perpetrators of harassment.

Our findings point to variation in the cultural context that make some fields, such as computer science, physics, and engineering, particularly hostile to women. In these fields, the goal should be to eventually recruit more women in cohorts with resources for mentoring and support. However, to do so without changing the cultural factors that drive women out is short-sighted. We should not encourage girls to pursue interests in these sciences and invest resources in training young women, if we cannot effectively change the factors that push them out, harm their health, and limit their career progression. We need to focus first on making disciplinary cultures more inclusive of women and taking concrete steps toward improved retention of the women already in these fields. If we can make changes to successfully retain women already in science, those women can serve as mentors and role models for younger women. Given the importance of social support in ameliorating the consequences of incivilities, and the ways in which social support leads to girls' persistence in STEM fields, these role models are a crucial step for success.

The problem of underrepresentation of women in science is often posed as a chicken and egg problem: Is the problem that there are not enough women interested in science, or that they are unwelcome? Our assessment of the literature is that, in most cases, the overwhelming issue is that women are made to feel unwelcome, in ways large and small, intentionally and unintentionally, across most scientific disciplines. The underlying reason that hostile behaviors continue, and disproportionately affect women of color, white women, and gender minorities, is that our incentive system derives from a male-dominated history and set of values: The gauntlet rests for men and takes up its arms against women. Disrupting the masculinity contexts at play in the sciences are necessary to create an inclusive environment that will enliven American science.

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