Why Are Some STEM Fields More Gender Balanced Than Others?

Sapna Cheryan and Sianna A. Ziegler
University of Washington

Amanda K. Montoya
The Ohio State University

Lily Jiang
University of Washington

Women obtain more than half of U.S. undergraduate degrees in biology, chemistry, and mathematics, yet they earn less than 20% of computer science, engineering, and physics undergraduate degrees (National Science Foundation, 2014a). Gender differences in interest in computer science, engineering, and physics appear even before college. Why are women represented in some science, technology, engineering, and mathematics (STEM) fields more than others? We conduct a critical review of the most commonly cited factors explaining gender disparities in STEM participation and investigate whether these factors explain differential gender participation across STEM fields. Math performance and discrimination influence who enters STEM, but there is little evidence to date that these factors explain why women's underrepresentation is relatively worse in some STEM fields. We introduce a model with three overarching factors to explain the larger gender gaps in participation in computer science, engineering, and physics than in biology, chemistry, and mathematics: (a) masculine cultures that signal a lower sense of belonging to women than men, (b) a lack of sufficient early experience with computer science, engineering, and physics, and (c) gender gaps in self-efficacy. Efforts to increase women's participation in computer science, engineering, and physics may benefit from changing masculine cultures and providing students with early experiences that signal equally to both girls and boys that they belong and can succeed in these fields.

Keywords: culture, gender, science, STEM, underrepresentation

Women now earn 37% of undergraduate STEM (science, technology, engineering, and mathematics) degrees in the U.S. (National Science Foundation, 2014a). But this statistic obscures an important observation: There are large differences in women's participation across STEM fields. While women have entered some STEM fields to the point where they are no longer underrepresented at the undergraduate level (e.g., biology), they have largely forsaken other STEM fields (e.g., computer science). Why are some STEM fields more gender balanced than others? In this review paper, we explore variation in rates of women's participation between STEM fields and propose a model to explain this variation.

Most previous work has treated STEM as a monolithic category (e.g., Ehrlinger & Dunning, 2003; Park, Young, Troisi, & Pinkus, 2011) or focused specifically on one STEM field (e.g., Cheryan, Plaut, Davies, & Steele, 2009; Good, Rattan, & Dweck, 2012). In the present work, we examine differences between STEM fields to shed light on why some fields are able to attract and retain women more successfully than others. From a theoretical perspective, disaggregating STEM fields provides an analytical lens through which to evaluate the most likely causes of current underrepresentation. For instance, women receive a significantly greater proportion of bachelor's degrees in mathematics (44%) than computer science (18%; National Science Foundation, 2014a), suggesting that gender differences in math ability do not account for the gender imbalance in computer science. From a practical standpoint, our analysis indicates which fields may need the most immediate attention, identifies which factors are most implicated in causing current disparities, and makes recommendations on how to best effect change to reduce gender disparities in current STEM participation.

Theoretical Framework

Reviews in psychology on women's underrepresentation in STEM have offered many useful insights by focusing on women's attitudes, backgrounds, and educational trajectories (e.g., Ceci, Ginther, Kahn, & Williams, 2014; Ceci, Williams, & Barnett, 2009; Eccles, Barber, & Jozefowicz, 1999; Spelke, 2005). For instance, Ceci et al. (2009) reviewed which factors across development (from prenatal hormones to tenure rates) contribute to

women's underrepresentation among STEM faculty. They conclude the following:

> To summarize our conclusions regarding the underrepresentation of women in math-intensive fields, we note that a powerful explanatory factor is that mathematics-capable women disproportionately choose nonmathematics fields and that such preferences are apparent among math-competent girls during adolescence. (Ceci et al., 2009, p. 251)

However, they do not address why these preferences are there in the first place, and why gender differences in preferences for computer science are so different from gender differences in preferences for mathematics. Our analysis shifts the lens from *women's trajectories* to the *cultures of fields* to investigate why some fields have achieved greater parity whereas others continue to have significant gender gaps in participation. In doing so, our analysis reveals that women's and men's preferences do not develop in a vacuum but are constrained and expanded by cultural factors.

Culture is a dynamic system consisting of individual behaviors and psychological tendencies that influence, and are influenced by, historically derived ideas and values, everyday interactions, and societal structures (Fiske & Markus, 2012; Markus & Conner, 2014; Markus & Hamedani, 2007). The culture of STEM is often spoken about as a uniformly hostile place for women—as a "chilly climate" (Seymour & Hewitt, 1997). However, recent evidence points to the fact that STEM fields can have very different cultures from one another when it comes to gender (Cohoon, 2002; Deemer, Thoman, Chase, & Smith, 2014; Leslie, Cimpian, Meyer, & Freeland, 2015). For instance, STEM fields differ in the extent to which they are associated with masculine stereotypes (Leslie et al., 2015; Matskewich & Cheryan, 2016). In addition, STEM cultures are located within a larger cultural context that contains a system of gender stereotypes, prescriptions, and practices (Prentice & Carranza, 2002; Ridgeway, 2001; Wood & Eagly, 2012). Even if the culture of a STEM field is not overtly hostile to women, women will be less likely to enter, persist, and be successful in a field when there is a mismatch between the way that they wish to be seen and are expected to behave (e.g., modest) and the norms of that culture (e.g., acting confident; Stephens, Fryberg, Markus, Johnson, & Covarrubias, 2012). Moreover, even in the absence of deterrents to women, a culture could still cause gender disparities by disproportionally attracting men.

Comparing fields to one another necessitates a sociocultural analysis in which both individual characteristics and beliefs (i.e., microlevel factors) and the social worlds and structures relevant to the field (i.e., macrolevel factors) are investigated together to explain disparities in a particular field (see Figure 1; Stephens, Markus, & Fryberg, 2012). According to Stephens, Markus, and Fryberg (2012), microlevel factors are characteristics or attributes of individuals whereas macrolevel factors are environmental conditions. To illustrate why a sociocultural analysis that takes both individual and social and structural factors into account is useful, consider the limited explanation for women's underrepresentation provided by David Gelernter, professor of computer science at Yale:

> The real explanation is obvious: Women are less drawn to science and engineering than men. . .they must be choosing not to enter, presumably because they do not want to; presumably because (by and large) they do not like these fields or (on average) do not tend to excel in them. (Gelernter, 1999)

Dr. Gelernter explains women's underrepresentation by focusing on individual preferences and abilities (i.e., women do not like science and engineering and are not very good at them). However, this
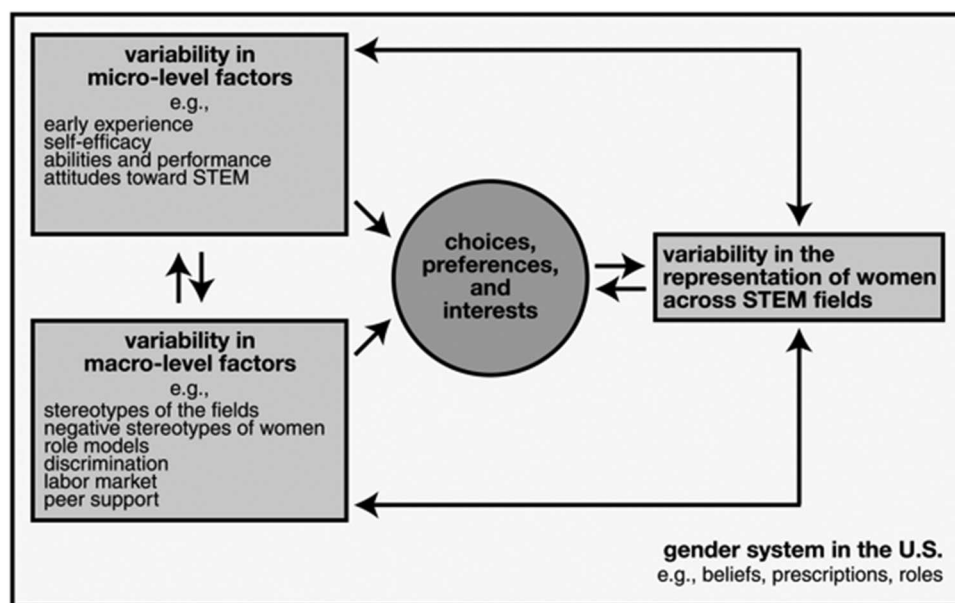

Figure 1. Sociocultural analysis of variability in gender representation takes into account both microlevel cultural factors (i.e., individual beliefs and characteristics) and macrolevel cultural factors (i.e., social and structural worlds) of STEM. These factors operate within a larger gender system in the U.S. Adapted from Stephens, Markus, and Fryberg (2012).

account fails to explain why women and men have different preferences in the first place. Our work approaches the problem of women's underrepresentation by using a "wide-angle lens" (Fiske & Markus, 2012, p. 3), investigating both microlevel and macrolevel factors that explain gender differences in participation across STEM fields. As we will see below, students' choices are made within a larger social and structural environment in which barriers to entering some STEM fields are significantly higher for women than men. These social and structural factors operate in tandem to pull girls and women (and boys and men) toward some STEM fields while pushing them away from others. Interventions that influence individual girls and women may not be effective in reducing gender disparities if broader cultural factors that shape women's participation in the field are not also taken into account.

How Does Women's Underrepresentation Differ Across STEM?

We investigate the six largest natural science and engineering fields at the college level (collapsing across engineering), as identified by the National Science Foundation (NSF, 2014c). Smaller STEM fields such as astronomy and atmospheric sciences have received relatively little attention in the literature on gender disparities and thus are absent from our review. We also exclude agricultural sciences, the third largest natural science according to the NSF, because of the minimal research on gender disparities in this field. From largest to smallest in bachelor's degrees granted, STEM fields included in our analysis are: biological sciences, engineering, computer science, mathematics and statistics,[1] chemistry, and physics. Though there are also important variations within these fields (e.g., women obtain 30% of bachelor's degrees in chemical engineering but 11% in electrical engineering; National Science Foundation, 2014a), the empirical literature to date has done little to examine these variations.

Looking at the percentage of bachelor's degrees in STEM that are received by women reveals two relevant findings. First, biological sciences, chemistry, and mathematics and statistics are gender-balanced (or nearly so) whereas computer science, engineering, and physics are highly male-dominated (see Figure 2).
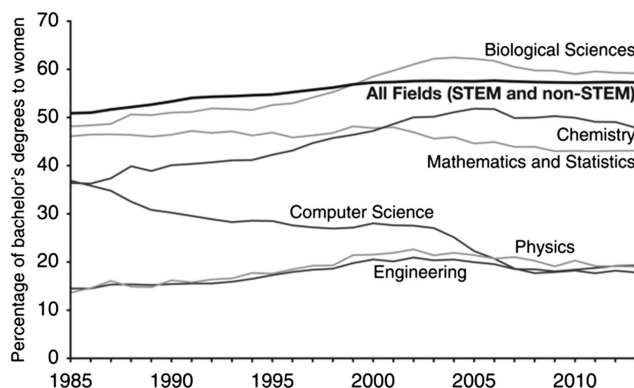

Figure 2. Percentage of bachelor's degrees awarded to women in STEM fields from 1985–2013. SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Integrated Science and Engineering Resources Data System (WebCASPAR), https://webcaspar.nsf.gov.

Second, trends over time reveal increases in the proportion of women in biological sciences and chemistry over the past three decades, but little gain in physics, engineering, and mathematics and statistics during this same period. For example, growth in percentage of bachelor's degrees earned by women in biological sciences and chemistry between 1985 and 2013 (11% and 12%, respectively) was more than double the increase in physics and engineering (both 5%; National Science Foundation, 2014a). This increase in women's representation in physics and engineering is similar to the percentage increase of all bachelor's degrees going to women (6% over that same time period). Women's participation in computer science has followed a unique trajectory: It is the only field to have experienced a marked decrease in the percentage of bachelor's degrees earned by women during the last three decades (a point we return to later in the review). By the mid-2000s, the percentage of bachelor's degrees in computer science earned by women had dropped by nearly half to around 20% to meet physics and engineering. Since the mid-2000s, no STEM field has seen much change in the percentage of bachelor's degrees going to women.

Women's participation in STEM fields today therefore is more concentrated in biology, chemistry, and mathematics than in computer science, engineering, and physics. Gender gaps in the latter fields are problematic for several reasons. First, fields themselves are missing out on potential contributions of talented women and on benefits of having gender diversity, including greater innovation, creativity, and collective intelligence (Page, 2007; Woolley, Chabris, Pentland, Hashmi, & Malone, 2010). In addition, women may be missing out on careers that are lucrative and high in status (Graves, 2014). Finally, the U.S. is not training enough computer scientists and engineers to keep up with demand (Bureau of Labor Statistics, 2014), and one way to remedy this is to make these fields more appealing to a broader audience.

In separating these fields, we are not suggesting that biology, chemistry, and mathematics have no remaining gender issues. Women are still vastly underrepresented in these fields as faculty (Ceci et al., 2009) and continue to face discrimination in these fields (Moss-Racusin, Dovidio, Brescoll, Graham, & Handelsman, 2012). However, at the undergraduate level, analyzing fields with a higher proportion of female graduates (>40%) separately from those with a lower proportion of female graduates (<20%) provides useful insights into the features that have allowed some fields to diversify more successfully than others.

Do Patterns of Underrepresentation Hold Across the Pipeline?

Women's underrepresentation in computer science, engineering, and physics is evident in high school, as indicated by who takes Advanced Placement (AP) examinations to earn college credit. Girls make up the majority of Biology AP test takers and approximately half of AP Chemistry, Statistics, and Calculus AB test takers (College Board, 2013). Girls are somewhat less likely than

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[1] NSF groups mathematics and statistics together. The relatively high representation of women in mathematics and statistics at the undergraduate level is not attributable to this grouping. In 2013, women received 44% of bachelor's degrees in mathematics and 45% of bachelor's degrees in statistics (National Science Foundation, 2014a).

boys to opt into the more advanced Calculus BC exam (40% girls; College Board, 2013). The proportion of female AP test takers is lower for computer science (19%) than for any other STEM field. The two AP Physics C exams are the next lowest (electricity and magnetism: 23%; mechanics: 26%), followed by the Physics B exam (35%; College Board, 2013).

Looking at intended majors among freshmen at postsecondary U.S. institutions tells a similar story (see Figure 3). Women make up more than half of first-year students intending to major in biological and agricultural sciences and more than 40% of first-year students intending to major in mathematics and statistics. However, most first-year students who intend to major in engineering are men, with women making up only 21%. The proportion of intended computer science majors who are women is even lower at 14% (National Science Foundation, 2012; Pryor, Hurtado, DeAngelo, Blake, & Tran, 2010).[2]

Figure 3 reveals a second important observation. The greater gender disparity in computer science relative to mathematics is not only a result of women's choices not to major in computer science, but also due to so many men choosing computer science. The number of women intending to major in mathematics is somewhat greater than the number of women intending to major in computer science, but the number of men intending to major in computer science is *much* higher than the number of men intending to major in mathematics. When theorizing about gender disparities in STEM, it is tempting to shine the light on women to provide the explanation (D. T. Miller, Taylor, & Buck, 1991), but men's choices matter just as much as women's choices in shaping underrepresentation. In this paper, we not only discuss contributors to women's interests and choices, but additionally consider how men's preferences and choices are influenced by cultural factors.
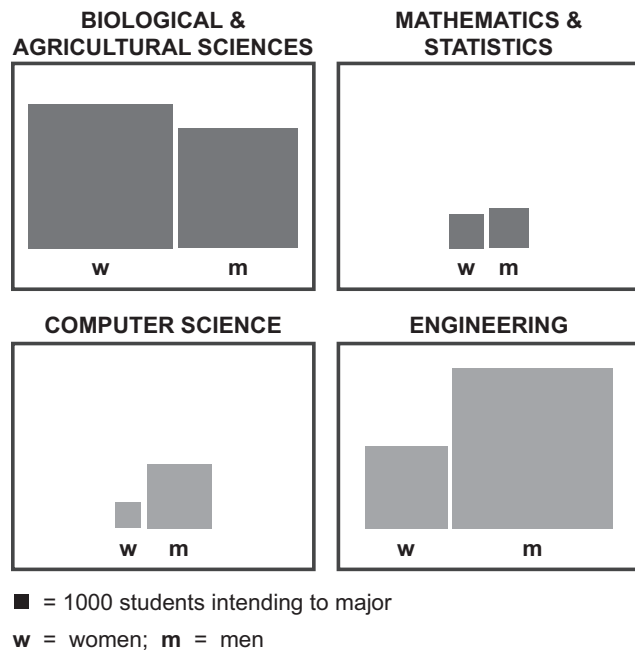
The rates at which girls and boys take AP computer science and physics exams and at which freshmen women and men report intending to major in computer science and engineering are quite similar to the proportion of women and men who go on to earn bachelor's degrees in these fields. The lower representation of women in computer science, engineering, and physics compared with biology, chemistry, and mathematics holds for all racial groups (National Science Foundation, 2014b), but gender disparities in computer science, physics, and engineering is greater among Whites than among African Americans, Latinos, Native Americans, and Asian Americans (see Table 1). The greater representation of African American and Latino women in these fields is in part a reflection of a higher representation of African American and Latino women earning college degrees relative to African American and Latino men (National Science Foundation, 2014b).

The proportion of women completing degrees in computer science, engineering, and physics does not decline markedly across different levels of higher education (see Figure 4). In fact, the proportion of women earning master's and doctoral degrees in computer science is higher than the proportion of women earning bachelor's degrees, which in turn is higher than the proportion of women who intended to major in computer science as freshmen. This suggests that academic computer science is actually losing proportionally more men than women. However, it is possible this pattern is itself symptomatic of gender disparities, as men may be more likely than women to find a computing job with less education. It is also possible that the smaller disparities in attrition in computer science, engineering, and physics are attributable to these departments working harder to retain the women they have or recruiting more women from other departments for graduate school.[3] Additionally, women who choose to enter fields where they are most underrepresented in spite of initial barriers to their participation may be more resistant to attrition in the face of subsequent obstacles.

Taken together, AP and college degree data suggest that girls and women are underrepresented in computer science, engineering, and physics—but relatively well-represented in biology, chemistry, and mathematics—from high school through graduate school. Moreover, computer science, engineering, and physics do not have higher attrition of female students than male students between high school and the time they finish college. The current underrepresentation of women and overrepresentation of men in these fields appears to be more of a recruitment issue (getting equal numbers of women and men to initially major in these fields) than a retention issue (keeping equal numbers of women and men there; see D. I. Miller & Wai, 2015, for a similar point using a retrospective analysis). Ensuring adequate retention is important because encouraging more girls and women into these fields by reducing barriers to entry would do little good if they are discour-

BIOLOGICAL & AGRICULTURAL SCIENCES

MATHEMATICS & STATISTICS

w   m

w   m

COMPUTER SCIENCE

ENGINEERING

w   m

w   m

■ = 1000 students intending to major

w = women; **m** = men

Figure 3. Number of female and male freshmen intending to major in STEM fields in 2010. SOURCE: National Science Foundation (2012). Raw numbers based on weightings from Pryor et al. (2010).

[2] Data for chemistry, earth sciences, physics, and astronomy are combined into the physical sciences. Women made up more than 40% of freshmen intending to major in this collection of fields.

[3] Computer science, engineering, and physics departments are not recruiting proportionally more international women into their departments than biology, chemistry, and mathematics. In 2013, 21% of the international students getting PhDs in computer science, engineering, and physics and 44% of the international students getting PhDs in biology, chemistry, and mathematics were women (National Science Foundation, 2014b).

Table 1

Percentage and Number of U.S. Bachelor Degrees in Computer Science/Engineering/Physics, Biology/Chemistry/Mathematics, and All Fields (STEM and non-STEM) Granted to Women in 2013 by Racial Group and for Temporary Residents

Racial group	Computer science, engineering, physics		Biology, chemistry, mathematics		All fields	
	%	N	%	N	%	N
American Indian/Alaska Native	24%	155	56%	380	60%	6,426
Asian American	22%	3,235	54%	10,762	54%	63,680
African American	26%	2,375	67%	6,380	65%	116,345
Hispanic or Latino	21%	2,710	58%	7,381	61%	118,216
Native Hawaiian/Other Pacific Islander	18%	66	55%	174	56%	2,774
White	17%	14,653	54%	44,658	56%	646,667
Temporary resident	21%	2,023	54%	3,303	50%	32,531

Note. SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Integrated Science and Engineering Resources Data System (WebCASPAR), https://webcaspar.nsf.gov.

aged from staying. However, recruiting more girls and women into computer science, engineering, and physics may be a necessary first step to increasing the number of women in these fields. In contrast, those interested in women's representation in biology, chemistry, and mathematics may benefit most from focusing more on retention than recruitment. Girls are about as likely as boys to take AP exams in these subjects, but the proportion of women declines with each subsequent stage of education, with the lowest proportion completing their doctorate.

Scope

We define the scope of our analysis as follows: First, we focus on gender disparities in the U.S., though we include comparisons to other countries as additional evidence. Second, a great deal of research has looked at how to explain gender disparities in STEM performance (e.g., Buday, Stake, & Peterson, 2012; Downey & Vogt Yuan, 2005; Logel et al., 2009; Nosek et al., 2009). However, our analysis examines factors explaining gender gaps in *academic participation* rather than in performance. Thus, we focus primarily on research that explains educational choices, preferences, and

Figure 4. Percentage of bachelor's, master's, and doctoral degrees awarded to women in STEM fields in 2013. SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Integrated Science and Engineering Resources Data System (WebCASPAR), https://webcaspar.nsf.gov.

interests, all of which are strong predictors of academic participation in the U.S. (Hidi, 2006; Hidi & Harackiewicz, 2000; C. L. Morgan, Isaac, & Sansone, 2001). Third, we focus on why gender disparities in STEM participation exist among students. Researchers who examine different populations (e.g., the STEM workforce) may draw different conclusions.

Proposed Model Explaining Women's Varying Representation in STEM Fields

There have been several proposed theories to explain why women are underrepresented in STEM (e.g., Ceci et al., 2009; Eccles, 1994; Gottfredson, 1981; Lent, Brown, & Hackett, 1994; Lent, Lopez, Sheu, & Lopez, 2011; Nosek et al., 2009; M. T. Wang, Eccles, & Kenny, 2013). Our paper makes three contributions beyond these previous analyses. Ours is the first review paper to disaggregate STEM fields and compare them with one another. From a theoretical standpoint, disaggregating fields allows us to identify likely causes of girls' and women's underrepresentation by investigating which factors are most prominent in fields with the biggest gender gaps. Second, our paper encompasses findings from four disciplines. Such breadth enables us to evaluate both microlevel (e.g., self-efficacy) and macrolevel (e.g., course offerings) contributors to women's underrepresentation. Third, previous reviews (Ceci et al., 2009; Su, Rounds, & Armstrong, 2009) identified women's and men's preferences as the main cause of women's underrepresentation. Differing preferences accurately explain women's and men's choices but previous analyses have not identified *why* their preferences differ and whether these preferences can and should be changed in the future.

We propose a parsimonious explanation for why some STEM fields are more gender balanced than others. As we will detail in the following sections, three overarching factors contribute to women's greater underrepresentation in computer science, engineering, and physics than in biology, chemistry, and mathematics (see Figure 5): (a) a masculine culture of computer science, engineering, and physics that signals to women a lower sense of belonging than to men, (b) insufficient early educational experience in computer science, engineering, and physics, and (c) larger gender gaps in self-efficacy in computer science, engineering, and physics.
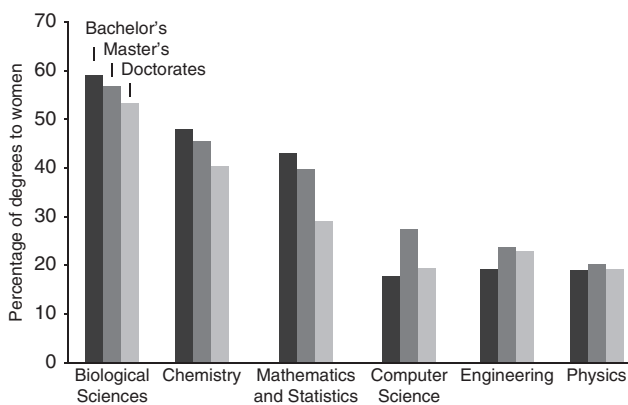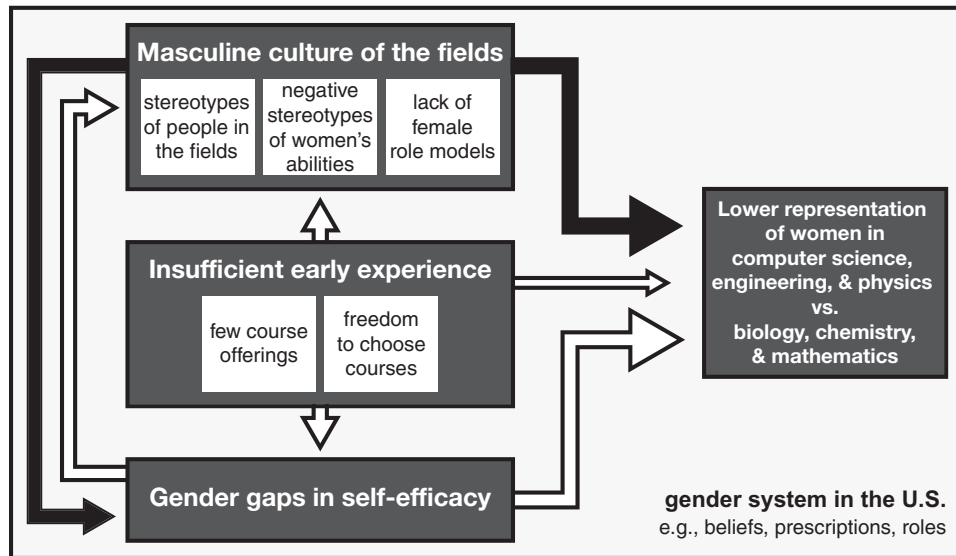
Figure 5. Masculine culture, insufficient early experience, and gender gaps in self-efficacy come together to explain women's lower representation in computer science, engineering, and physics than biology, chemistry, and mathematics. Solid arrows indicate the presence of experimental evidence.

We conceptualize masculine culture as features of a field (e.g., beliefs, norms, values, structures, interactions) that can cause women to feel a lower sense of belonging or be less successful than their male counterparts. Fields are embedded within a larger societal system of gendered beliefs and values that encourage and reward masculine characteristics in men and feminine characteristics in women (Eagly, 1987). As a result, it may be more difficult for women and girls to see themselves fitting into fields with masculine cultures, and they may be more likely to forsake these fields in favor of others with less masculine cultures. Note that we are not saying that all women are repelled by masculine cultures and all men are attracted by them. Some women may be attracted to fields with masculine cultures just as masculine cultures may repel some men. Changing cultures of computer science, engineering, and physics to feel more welcoming to a wider range of people may not only attract more women but also some men who do not feel like they fit well within the current cultures.

Turning to the second factor, students receive more early (i.e., precollege) educational experiences in some STEM fields than others. Early experience can counteract masculine cultures by changing stereotypes and exposing women to role models. STEM fields that are taught in an early and sustained fashion throughout schooling may be less likely to have gender gaps in college participation than STEM fields that are less commonly taught in high schools. Mandatory early experience in which girls perform as well as boys may also help to reduce gender gaps in self-efficacy.

However, as indicated by the smaller arrow between insufficient early experience and representation in our model, there are two reasons we believe that insufficient early experience by itself is a less potent explanation for gender disparities in participation than masculine culture. First, a lack of early experience does not in and of itself cause women's underrepresentation. There are many fields, such as psychology and nursing, in which students do not

get much early experience but which still attract women. It is only when a lack of early experience is present alongside a perceived masculine culture that gender disparities are observed. Second, despite the extensive experience that students get with mathematics throughout schooling, women continue to be underrepresented in math PhD programs (see Figure 4). Early educational experience may be a way to spark change in who participates, but cultural changes may be important to effect maximal change throughout educational pathways and beyond.

The third factor is gender gaps in self-efficacy, or disparities between men's and women's estimations of their own abilities. Fields with bigger gender gaps in self-efficacy generally have bigger gender gaps in participation. We include gender gaps in self-efficacy in our model because studies exist that support our inclusion criteria, though evidence is more mixed for this factor than the other two factors.

An analogy to swimming can illustrate how these three factors operate to produce and sustain gender disparities. A masculine culture can be thought of as the cold temperature of a swimming pool. If you think the water is very cold and you have been socialized to believe that you do not and should not like cold water, you may be reluctant to get in the pool. Early experience is analogous to being required to jump into the pool at a formative age. Imagine you jump in and find the water temperature is actually quite comfortable. You may be encouraged to continue swimming. However, if the temperature is as cold as you imagined or even colder, you may decide you are done and jump out. Gender gaps in self-efficacy are analogous to people of another gender rating their swimming abilities more favorably than people of your gender rate theirs. These beliefs may encourage more people of the other gender to jump in the pool, even if their swimming abilities are no better than the abilities of people of your gender. To encourage a wider range of people to swim, water temperature should be comfortable for everyone and perceived as such. Like-

wise, to close gender gaps in participation in computer science, engineering, and physics, cultures of these fields should signal equally to women and men that they belong and can achieve success in them.

Method

To identify factors that might explain variability in gender participation between STEM fields, the authors read review papers published since 1990 in psychology, education, and sociology on the topic of women's underrepresentation in STEM (Abbiss, 2008; Adya & Kaiser, 2006; Barker & Aspray, 2006; Blickenstaff, 2005; Buchmann, 2009; Ceci & Williams, 2010; Ceci et al., 2009; Cohoon & Aspray, 2006; Dryburgh, 2000; Grover & Pea, 2013; Gürer & Camp, 2002; Halpern et al., 2007; Howell, 1993; Ong, Wright, Espinosa, & Orfield, 2011; Saucerman & Vasquez, 2014; Shapiro & Sax, 2011; Singh, Allen, Scheckler, & Darlington, 2007; Sonnert, 2006; Spelke, 2005; Teague, 1997; M. T. Wang & Degol, 2013; Wentling & Thomas, 2004; Whitley, 1997). We could find no review papers in economics on this topic. Ten common contributing factors were identified from these papers: stereotypes of STEM fields, negative ability stereotypes and perceived bias, lack of role models, insufficient early experience, self-efficacy, formal discrimination, math ability and performance, labor market and institutional forces, peer support, and attitudes. When possible, each factor was separated into relevant subfactors (e.g., the stereotypes about STEM fields factor was separated into stereotypes about the people, stereotypes about the work, perceptions of work-family conflict, income potential, and value of STEM).

To collect articles, we searched psychology (PsycInfo), education (Education Resources Information Center; ERIC), sociology (Sociological Abstracts), and economics (EconLit) databases. Incorporating work from multiple fields enabled us to best evaluate evidence for or against a particular factor being able to explain gender disparities in participation. For an initial search of articles (performed in spring 2014), we searched each database for "Gender" and each of the following keywords: "STEM," "Biology," "Chemistry," "Math," "Computing," "Engineering," and "Physics." These search terms generated more than 20,000 hits. Research assistants and the second and third authors divided up the lists and reviewed titles and abstracts to narrow to articles relevant to gender disparities in academic STEM fields: 317 from PsycInfo, 586 from ERIC, 284 from Sociological Abstracts, and 25 from EconLit. To ensure we were not missing any relevant articles, we repeated database searches in December 2015 using the following title and keyword search terms: Gender (entered as "Gender*" to allow for plural or suffixes) or Sex Difference ("Sex Difference*") and each of the following terms: STEM, Science ("Scien*"), Biology ("Biolog*"), Chemistry ("Chemist*"), Mathematics ("Math*"), Computer Science ("Computer Scien*"), Computing, Engineering ("Engineer*"), and Physics ("Physic*" excluding "Physician*" and "Physical*"). We collected 2916 articles from PsycInfo, 1266 articles from ERIC, 3687 articles from Sociological Abstracts, and 235 articles from EconLit for a total of 8104 articles. The first and fourth authors reviewed titles to narrow to 298 articles after removing duplicates and overlaps with the first list (percent agreement between authors: 96.8; κ = .52). Abstracts were then retrieved and reviewed by the first and fourth authors for relevance (percent agreement: 86.3; κ = .64). Fifty-two articles were retrieved and added to the initial list of articles.

We supplemented our final list with relevant articles that did not appear in our database searches but were recently published, cited in the review papers, or pointed out to us by colleagues. We focused on papers published after 2000, but pre-2000 papers were included when more recent findings on the topic were unavailable or provided weaker evidence (e.g., did not use a national sample). Research assistants sorted articles into factors, with one author checking to make sure they were sorted appropriately. Articles relevant to more than one factor were put in multiple categories, and those relevant to none of the factors were grouped separately. To ensure included studies met a minimum threshold for quality, findings must have replications or meet a minimum sample size requirement (i.e., 20 participants per cell for *t* tests, ANOVAs, and chi-squared analyses; 50 for correlational data and longitudinal designs; at least 5 participants per cell for chi-squared analyses; Hedeker, Gibbons, & Waternaux, 1999; Simmons, Nelson, & Simonsohn, 2011; VanVoorhis & Morgan, 2007), excepting data that are difficult to collect (e.g., physiology data; Vazire, 2015). Studies that do not include appropriate control conditions or do not control for other important factors were not included or limitations were noted in the text.

Below we review factors that are thought to explain women's underrepresentation in STEM. Our goal is to assess how well each factor is able to explain current patterns of variability in gender participation in STEM. For a factor to satisfactorily explain variability in gender participation across STEM fields, it has to meet two criteria (see Table 2 for factors and criteria). First, the factor or its effects must distinguish computer science, engineering, and physics from biology, chemistry, and mathematics. For each factor, we start with evidence in computer science, engineering, and physics and then turn to biology, chemistry, and mathematics. Studies are included as potentially explaining variability if they explicitly compare STEM fields to one another (e.g., starting salary information), or if they provide evidence about one STEM field that can be compared with evidence from another STEM field (e.g., direction of math vs. engineering self-efficacy gender gap).

The second criterion is that the factor has to be related to gender differences in interest, intentions to major, or participation in STEM. Studies that fit this criterion have to measure the gender gap (i.e., include women and men as participants). We consider whether gender gaps exist in that factor, and we include effect sizes of the gender gap based on meta-analyses when available. We then consider both correlational and experimental evidence investigating whether differing levels of the factor predict gender gaps in interest or participation.

We begin with the factors related to masculine culture in our model (i.e., stereotypes about STEM fields, negative stereotypes and perceived bias, role models), then review evidence on early educational experiences (i.e., course offerings and freedom to choose courses), and then turn to self-efficacy. After reviewing the main factors, we review two factors (i.e., formal discrimination, math ability and performance) that do not meet at least one of the criteria and thus are less likely to explain current variability in gender participation in STEM fields. We then briefly review three factors (i.e., labor market and institutional forces, peer support, and attitudes) that have some promising evidence but not enough to meet our two criteria and conclude our paper with a discussion of

Table 2
Potential Factors Explaining Variability in Women's Underrepresentation Assessed by Two Criteria

	Masculine culture of fields								
	Stereotypes of the fields					Negative stereotypes and perceived bias		Lack of role models	
Criterion	About the people	About the work	Income potential	Work–family conflict	Value of fields	Negative stereotypes of women's abilities	Perceived gender bias & discrimination	Female role models	Relatable role models
Corresponds to variability	✓	×	✓	?	?	✓	?	✓	?
Gender disparities	✓	✓	×	✓	×	✓	✓	✓	✓

	Insufficient early experience with fields				Other factors	
Criterion	Few course offerings	Freedom to choose courses	Gender gaps in early educational experience	Gender gaps in self-efficacy	Formal discrimination	Math ability & performance
Corresponds to variability	✓	✓	✓	✓	×	×
Gender disparities	✓	✓	?	✓	✓	×

Note. Corresponds to variability = differs in computer science, engineering, and physics compared with biology, chemistry, and mathematics; Gender disparities = predicts gender disparities in interest or participation; ✓ = evidence exists in line with criterion; √ = factor meets criterion for some populations but not others; ? = insufficient evidence to determine whether criterion is met; × = factor does not meet criterion.

how our model may be applicable to other domains, including non-STEM fields and countries outside the U.S.

Masculine Culture

The type of masculinity associated with computer science, engineering, and physics differs from the traditional definition of masculinity that includes, for example, physical and sexual prowess (Bosson, Vandello, Burnaford, Weaver, & Arzu Wasti, 2009; Cheryan, Cameron, Katagiri, & Monin, 2015). In STEM fields, a masculine culture is a social and structural environment that confers a greater sense of belonging and ability to succeed to men than women.

Below we review three components of masculine culture (each is further divided): stereotypes of the field that are incompatible with the way that many women see themselves, negative stereotypes and perceived bias, and few role models for women.[4] These factors have been shown to decrease women's sense of belonging in a field. The lower one's sense of belonging in STEM, the less interest one expresses in entering and pursuing these fields (Cheryan & Plaut, 2010; Good et al., 2012; Thoman, Arizaga, Smith, Story, & Soncuya, 2014). However, masculine cultures are not foregone conclusions in these fields. Computer science is a good example of a field that shifted from a culture that was more welcoming to women to one that was "*made* masculine" (Ensmenger, 2010, p. 121; Misa, 2010).

Stereotypes of the Fields

Stereotypes are beliefs about a social group that are widely known and culturally shared (Fiske, 2010; C. M. Steele, Spencer, & Aronson, 2002). Current stereotypes of STEM fields include students' ideas about people who do STEM, stereotypes about the work, perceptions of income potential, perceptions of work/family

conflict, and how valuable fields are perceived to be. Stereotypes could contribute to gender disparities either if they have a different impact on women than they do on men, or if men and women hold different stereotypes. Stereotypes can be influential if students believe them (Prentice & Miller, 1996) or believe that others believe them (C. M. Steele et al., 2002), even if they are entirely inaccurate (Borg, 1999).

Stereotypes of the people in the fields. Stereotypes about the people include traits and characteristics that are associated with STEM majors and people in STEM careers.

Variability within STEM. There are two stereotypes about people in STEM that we consider. The first is an association of STEM fields with males. The second is a belief that people in STEM have masculine traits and interests.

Computer scientists, engineers, and physicists are seen as stereotypically male (Cheryan, Plaut, Handron, & Hudson, 2013; Haines & Wallace, 2003; Hoh, 2009; Knight & Cunningham, 2004; J. L. Smith, Morgan, & White, 2005). Though biology and chemistry are also associated with males (Finson, 2002; Picker & Berry, 2000; Smyth & Nosek, 2015), these fields are perceived to have a significantly lower proportion of men than computer science, engineering, and physics, with mathematics falling in between the two sets of fields (Matskewich & Cheryan, 2016). When asked to draw a mathematician, children in kindergarten and first grade are more likely to draw women than men, and children in second through fourth grades are equally likely to draw women and men (Rock & Shaw, 2000). Students' stereotypes about the proportion of men in a field thus correspond to current patterns of gender disparities within STEM, with computer science, engineer-

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[4] Formal discrimination against women is another component of masculine culture, but it is reviewed later in the paper because it did not meet both criteria to qualify for our model.

ing, and physics being stereotypically associated with males more than biology, chemistry, and mathematics. However, associations of biology and chemistry with males are weaker among African American women than among White women (O'Brien, Blodorn, Adams, Garcia, & Hammer, 2015). We could find no other work examining whether students' stereotypes of STEM fields differ based on other demographic factors such as race and class.

Turning to traits and interests, undergraduates (both women and men) stereotype computer scientists as socially awkward and singularly focused on technology (Beyer, DeKeuster, Walter, Colar, & Holcomb, 2005; Cheryan et al., 2009; Cheryan, Plaut, et al., 2013; Schott & Selwyn, 2000). Elementary and middle school students' perceptions of engineers are that they build and fix things such as cars (Fralick, Kearn, Thompson, & Lyons, 2009; Karatas, Micklos, & Bodner, 2008; Knight & Cunningham, 2004). We were unable to find studies of American students' stereotypes of physicists, but the popular American TV show *Big Bang Theory* depicts them as "clever and nerdy and hopeless with the opposite sex" ("Media Star," Nature Physics, 2008, p. 337). In the U.K., physicists are often portrayed as male, untidy, "fairly mad looking," and surrounded by explosions, atoms, and lightning (McAdam, 1990, p. 104).

Biologists, chemists, and mathematicians are also associated with masculine traits (Hughes, 2002), but these traits may be less masculine than those associated with computer scientists, engineers, and physicists. Elementary school students in Canada and the U.S. associate scientists with discovery and with instruments such as microscopes and telescopes (Chambers, 1983). Americans associate chemists with traits such as being innovative and results-oriented (National Science Foundation, 2002). Elementary school students in kindergarten through fourth grade most commonly portray mathematicians in a classroom (e.g., doing computations on a chalkboard), and over 80% of them portray someone smiling while doing math (Rock & Shaw, 2000). Middle school students from four different countries including the U.S. depict mathematicians as teachers (Picker & Berry, 2000). Biologists, chemists, and mathematicians are less associated with masculinity than computer scientists, engineers, and physicists (Matskewich & Cheryan, 2016). Stereotypes of the people in these fields thus correspond to current patterns of gender disparities, with the most male-dominated fields being associated with the most masculine traits.

Influence on gender disparities in participation. Correlational evidence suggests that implicit, or automatic, associations between STEM and males have negative consequences for women's science and math interests and aspirations. Undergraduate women, including those in introductory biology, chemistry, and physics classes, who have stronger implicit male-science associations identify less with science and have weaker science career aspirations than women with weaker implicit male-science associations (Cundiff, Vescio, Loken, & Lo, 2013; Lane, Goh, & Driver-Linn, 2012). High school girls report larger discrepancies between their self-views and perceptions of typical science students than do boys; these discrepancies in turn are associated with less interest in science (Lee, 1998). Women with higher implicit male–math associations whose identity as women is important to them are also less likely to declare an interest in pursuing math-based careers than women who hold lower implicit math-male associations or identify less strongly with their gender (Kiefer & Sekaquaptewa,

2007; see also Nosek & Smyth, 2011). Providing students with more science and mathematics experience may not weaken these stereotypes. College students in an introductory calculus course show *stronger* implicit male-math associations later in the term than at the beginning (Ramsey & Sekaquaptewa, 2011). However, women who choose to pursue STEM fields may associate themselves with the field more and show weaker implicit male-science associations than women not in STEM (Smyth & Nosek, 2015).

Stereotypes of the people in computer science being socially awkward, interested in science fiction, and obsessed with technology influence women's interest in entering these fields (Cheryan et al., 2009). Women who interact with a computer science major who embodies current stereotypes of computer scientists in appearance (e.g., glasses and a t-shirt that says "I code therefore I am") and hobbies (e.g., video games) express less interest in computer science than women who interact with a computer science major who does not embody these stereotypes. Gender of the computer science major has little effect on interest—women are equally deterred by women and men who embody the stereotypes (Cheryan, Drury, & Vichayapai, 2013). Men, however, are not deterred, and are even attracted by current computer science stereotypes (Cheryan, Drury, et al., 2013; Cheryan, Siy, Vichayapai, Drury, & Kim, 2011).[5] Women who have completed less previous computer science coursework have less stereotypical views of computer scientists (e.g., socially awkward, intensely focused on computers; Cheryan, Plaut, et al., 2013), though the direction of causality is unknown.

Physical environments that fit current computer science stereotypes can also be a deterrent to women. Undergraduate women—but not men—who enter a computer science classroom with objects that are consistent with current stereotypes (e.g., Star Trek posters and video games) are less interested in pursuing computer science than women who enter a classroom that does not fit current stereotypes (e.g., nature posters and magazines; Cheryan, Meltzoff, & Kim, 2011; Cheryan et al., 2009). Even computer science environments that are composed entirely of women can deter women if their environments fit current masculine stereotypes (Cheryan et al., 2009). Moreover, these stereotypes affect younger students: High school girls who see a classroom that contains objects stereotypically associated with computer scientists express significantly less interest in enrolling in an introductory computer science course than high school girls who see a classroom with nonstereotypical objects. There is no significant effect of the stereotypical classroom environment on high school boys (Master, Cheryan, & Meltzoff, 2016).

Computer science stereotypes deter women more than men because they are more incompatible with the way that women see themselves and would like to be seen by others (Cech, 2013; Cejka & Eagly, 1999; Cheryan et al., 2009). When these stereotypes are salient, women's sense of belonging in the field decreases (Cheryan, Master, & Meltzoff, 2015; Cheryan et al., 2009; Master et al., 2016). Having a sense of belonging in a field is a strong predictor of interest (Cech, Rubineau, Silbey, & Seron, 2011;

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[5] It is not the case that all women and all men respond the same way to the stereotypes. Some women are attracted to the current stereotypes just as some men are deterred by them. Diversifying current stereotypes so that students do not think they must fit this image to be successful in computer science may help to attract more men and women into these fields.

Cheryan & Plaut, 2010; Cheryan et al., 2009; Good et al., 2012; Walton & Cohen, 2007). These stereotypes also cause women to believe that they might be judged negatively by potential romantic partners for choosing a stereotypically masculine field (Park et al., 2011). Broadening the image of computer science beyond the masculine stereotypes by using computer science environments, curriculum, role models, and the media can motivate girls' interest in learning computer science (Cheryan, Master, et al., 2015; Lynn, Raphael, Olefsky, & Bachen, 2003).

Stereotypes about the work in the fields. Cultural stereotypes about the work involved in these fields and what is required to succeed in them differ across STEM fields.

Variability within STEM. There are three stereotypes about the work that have been theorized to explain gender disparities in STEM. The first is whether the content of the work is mostly people-oriented or mostly thing-oriented (Diekman, Brown, Johnston, & Clark, 2010; Su et al., 2009). The second is whether the work fulfills goals of achieving power and status (Gino, Wilmuth, & Brooks, 2015). The third is a belief that achieving success in the field requires inborn genius or brilliance (Leslie et al., 2015).

First, among undergraduates, stereotypes that pursuing the field will allow fulfillment of people-oriented goals such as affiliation, intimacy, and altruism are weakest in mathematics and strongest in biology, with computer science and engineering falling in between the two fields (Matskewich & Cheryan, 2016; see also Masnick et al., 2010; Weisgram & Bigler, 2006). Differing preferences for people-oriented jobs cannot fully explain current patterns (e.g., why women are better represented in mathematics than computer science and engineering) or within-field variations (e.g., higher proportion of women in materials engineering than electrical engineering; Yoder, 2011).[6]

Second, undergraduates expect that majoring in computer science and engineering will fulfill goals for power, achievement, and excitement more than majoring in mathematics, but biology is expected to fulfill these goals at least as much as computer science (Matskewich & Cheryan, 2016). Power-seeking thus cannot explain why gender disparities in participation are lower in computer science and engineering than biology and mathematics.

Third, computer science, engineering, and physics are perceived as fields that require innate talent or "genius" more than other fields such as biology and chemistry, but mathematics is perceived as requiring at least as much innate talent as computer science, engineering, and physics (Leslie et al., 2015). Stereotypes that the fields require an innate talent thus does not fully correspond to current patterns of gender disparities within STEM fields.

Influence on gender disparities in participation. Women's preferences for people versus men's preferences for things is a large effect ($d = 1.18$ in Lippa, 2010; $d = .93$ in Su et al., 2009) that has been cited to explain gender disparities in STEM (Lippa, 1998; Su et al., 2009). Women are more likely than men to endorse people-oriented goals in choosing a career, including wanting to work with and help others (Diekman et al., 2010). A meta-analysis showed that high school girls have stronger preferences than boys for jobs that involve working with ($d = .36$) and helping ($d = .45$) people (Konrad, Ritchie, Lieb, & Corrigall, 2000). Among STEM majors, women report more interest than men in people- and helping-oriented aspects of these majors (P. H. Miller, Blessing, & Schwartz, 2006; P. H. Miller, Rosser, Benigno, & Zieseniss, 2000; Yang & Barth, 2015). Female biology majors report the same level

of interest in people-oriented jobs as other female STEM majors but lower interest in thing-oriented jobs (Yang & Barth, 2015).

A national longitudinal study conducted between 1985 and 1994 found that female science, engineering, and mathematics majors who have a greater desire to make a difference in society are less likely to go on to graduate school in their fields than women for whom this goal is less important (Sax, 2001). The more women endorse goals to help and work with people, the lower their interest in computer science, engineering, mathematics, and physical sciences (Diekman et al., 2010; see also Cech, 2013). Women, but not men, who read about a scientist engaging in everyday collaborative tasks feel more positively about being a scientist than women who read about a scientist engaging in independent tasks (Diekman, Clark, Johnston, Brown, & Steinberg, 2011).

With respect to power goals, undergraduate men are more likely than undergraduate women to report that having power in their future careers is an important goal (Evans & Diekman, 2009; Gino et al., 2015), and this gender difference mediates men's greater preference for male-stereotypic careers (e.g., corporate lawyer, finance; Evans & Diekman, 2009).

Finally, the notion that success in computer science, engineering, physics, and mathematics requires innate genius may deter women, especially when negative stereotypes about women's abilities are prominent (Good et al., 2012; Leslie et al., 2015). Girls and women are more likely than boys and men to believe that their success is attributable to hard work rather than natural ability (Gilbert, 1996; Kiefer & Shih, 2006). The more women perceive that being successful in STEM requires relatively more effort by them compared with their peers, the less motivated they are to pursue these fields (J. L. Smith, Lewis, Hawthorne, & Hodges, 2013), but making effort seem expected and normal increases women's motivation to pursue STEM (Perez-Felkner, McDonald, Schneider, & Grogan, 2012; J. L. Smith et al., 2013). The mindset that success requires hard work rather than innate ability also helps students persist in the face of challenges (Good et al., 2012). Belief that innate brilliance is required for success in STEM may prevent women from being as successful as men.

Income potential. Are some STEM fields seen as affording greater income, and is there evidence that higher earning potential disproportionally attracts men?

Variability within STEM. Approximate median salaries for people ages 25 to 59 with undergraduate degrees in computer science ($83,000), architecture and engineering ($83,000), and physics ($81,000) are notably higher than median salaries for those with degrees in biology ($56,000), chemistry ($64,000), and mathematics ($73,000; Carnevale, Cheah, & Hanson, 2015). This factor distinguishes fields with proportionally more men from fields with proportionally more women.[7] One caveat regarding this analysis is that it is unclear how much knowledge students have about salary differences between some STEM fields (e.g., chemistry vs. engineering; Betts, 1996).

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[6] Another critique of the people-things dichotomy is that the labels are inaccurate and misleading (e.g., "things" is defined narrowly and does not include less masculine items such as food and clothing; Valian, 2014).

[7] Salary does not appear to explain women's underrepresentation in philosophy. The median salary for people with undergraduate degrees in philosophy and religious studies ($51,000) is lower than median STEM ($76,000) and liberal arts ($53,000) salaries (Carnevale et al., 2015).

Influence on gender disparities in participation. A meta-analysis of 21 nationally representative samples of high school seniors between 1975 and 1996 revealed that boys have stronger preferences for jobs with high earning potential than do girls (Hedges $g = .21$; Konrad, Ritchie, et al., 2000), and this preference has been seen in more recent samples as well (Heckert et al., 2002; C. L. Morgan et al., 2001; Weisgram, Dinella, & Fulcher, 2011). However, a high salary does not appear to be a stronger predictor of interest for men than women (Howard et al., 2011; C. L. Morgan et al., 2001). There is little evidence that low salaries attract women and repel men out of occupations (Levanon, England, & Allison, 2009). The tendency for female-dominated occupations to have lower salaries is better explained by a devaluation of occupations that have more women (Levanon et al., 2009). Women's returns in STEM are not as high as men's, as measured by starting salaries, and controlling for this disparity reduces effects of gender on choosing a STEM field relative to a social science field (Staniec, 2004). Taken together, evidence suggests that salary differences may be the outcome of gender disparities rather than the cause and that earnings may be important to both men and women.

Perceptions of work/family conflict. Beliefs that pursuing a career is incompatible with having a family has been theorized to be an important factor in preventing women from pursuing STEM careers (e.g., Ceci et al., 2009).

Variability within STEM. We could find no evidence for whether women perceive greater work/family conflict in computer science, engineering, and physics than biology, chemistry, and mathematics. Even so, women now participate at rates comparable with men in other fields with demanding career prospects and long work hours, such as medicine and law, so it seems unlikely that perceptions of work/family compatibility alone can explain why many women forsake majors in computer science, engineering, and physics.

Influence on gender disparities in participation. Girls perceive work/family conflict as a problem for other women, but this conflict may not strongly influence their own educational decisions early in life. High school girls rate having children as more important to them than do high school boys, but this accounts for less than 2% of the gender gap in choosing a STEM major (including doctoral-level medical tracks; S. L. Morgan, Gelbgiser, & Weeden, 2013; see also Mann & DiPrete, 2013). Although nearly half of the undergraduate engineering students surveyed at a public university cited possible conflicts between career and family responsibilities as a major problem for women pursuing careers in science, engineering, and mathematics (Hartman & Hartman, 2008), freshman women's intentions to start a family did not predict their persistence in undergraduate engineering programs (Cech et al., 2011). In a sample of undergraduates in introductory STEM classes, men are more likely than women to indicate that having a satisfying family life with time for leisure activities is their most important life goal whereas women are more likely than men to cite helping people as their most important life goal (Barth, Todd, Goldston, & Guadagno, 2010). However, among another sample of undergraduates, prioritizing family over career predicts a marginally significant lower likelihood of taking a subsequent computer science class, and women are significantly more family oriented than men (Beyer, 2014).

As female undergraduate computer science majors advance in their program, they become more pessimistic that women can successfully combine having a career in their field with family life (Beyer et al., 2005; but see Haines & Wallace, 2003). Female graduate students are less likely than their male peers to see careers in STEM fields as compatible with having a family (Ferreira, 2003). Women majoring in science, engineering, and mathematics who report that having a family is a higher priority for them are less likely to attend graduate school than women who report that having a family is a lower priority (Sax, 2001). Married women with children are more likely to leave science and engineering after receiving their master's degrees than are women without children or married men with children (Xie & Shauman, 2003). While male and female students in top mathematics and science graduate programs rate having a flexible schedule and limited work hours as equally important at age 25, the importance of these factors increases for women—but not men—over time (Ferriman, Lubinski, & Benbow, 2009). As women progress in their education, the work/family conflict may become a bigger deterrent.

Perceptions of the value of STEM. The extent to which students believe a field is valuable, important, and useful influences which courses they choose and careers they pursue (Eccles, 1994).

Variability within STEM. We could find no evidence comparing students' beliefs about how valuable computer science, engineering, and physics are relative to biology, chemistry, and mathematics.

Influence on gender disparities in participation. Elementary, middle, and high school girls typically rate science and mathematics as *more* important subjects for them than boys do (Else-Quest, Mineo, & Higgins, 2013; Selkirk, Bouchey, & Eccles, 2011; Teshome, Maushak, & Athreya, 2001; but see Chow, Eccles, & Salmela-Aro, 2012, for boys with higher value of mathematics and physical sciences). High school girls report valuing science more highly than boys across racial groups (i.e., African American, Latino, Asian American, and White; Else-Quest et al., 2013). High school girls and boys are also equally likely to appreciate the value of computers (Shashaani, 1993, 1994). Male and female college students in introductory psychology (Whitley, 1996) and computer science (Shashaani, 1997) courses are equally likely to rate computers as useful and knowledge about computers as important in obtaining a job. However, college women may have more negative beliefs than men about the impact of computers on social interactions (e.g., that they will lessen the importance of people; Whitley, 1996). Valuing school, including science and mathematics, may be considered appropriate for girls, and may be seen as even more appropriate for girls than boys (Cheryan, 2012).

Interventions to change the extent to which students value science and find it relevant have worked to increase students' interest in science, but boys and girls appear to equally benefit from these interventions (Hulleman, Godes, Hendricks, & Harackiewicz, 2010; Hulleman & Harackiewicz, 2009; but see Rozek, Hyde, Svoboda, Hulleman, & Harackiewicz, 2015). This is consistent with the finding that girls and boys do not differ on how much they value these fields or consider them important to their lives.

Summary. Evidence suggests that stereotypes of the people as male, socially awkward, and focused on technology meet both criteria to be included in our model. These stereotypes are more

prominent in computer science, engineering, and physics than in biology, chemistry, and mathematics, and they have been shown to cause gender disparities in interest. These stereotypes are less compatible with the female than male gender role (Cheryan, Master, et al., 2015). As a result, women are less likely than men to believe they fit these stereotypes and more likely to be deterred when stereotypes are salient. However, these stereotypes are readily changed by altering physical environments, media, and role models (Cheryan, Master, et al., 2015).

Stereotypes about computer science, physics, and engineering not being people-oriented and requiring innate ability may be contributing to gender differences in interest. But these stereotypes may be just as strong in mathematics as computer science, physics, and engineering and thus may not explain why mathematics is more gender balanced than these other fields. Evidence to date suggests that two other work-related perceptions—income potential and how valuable the fields are—do not appear to explain current variability in gender gaps in STEM participation.

Negative Stereotypes and Perceived Bias

Women are negatively stereotyped in U.S. culture as having lower abilities in mathematics and science than men (Dar-Nimrod & Heine, 2006). Knowledge that others are negatively stereotyping their gender can prevent women from being interested in pursuing STEM (J. L. Smith, Sansone, & White, 2007). In addition, the possibility of encountering bias and discrimination because of negative stereotypes reduces women's sense of belonging in STEM (Ahlqvist, London, & Rosenthal, 2013; Good et al., 2012).

Negative stereotypes of women's abilities. Women face negative stereotypes about their lack of competence in STEM (Spencer, Steele, & Quinn, 1999). Stereotype threat is the fear of confirming negative stereotypes about one's group (C. M. Steele et al., 2002).

Variability within STEM. Stereotype threat can be induced when women are underrepresented in a situation (Inzlicht & Ben-Zeev, 2000; Murphy, Steele, & Gross, 2007; Sekaquaptewa & Thompson, 2003; Shaffer, Marx, & Prislin, 2013), suggesting that women may experience stereotype threat more often in fields in which the proportion of women is lower. Indeed, undergraduate women report greater concerns about being stereotyped negatively because of their gender in computer science, engineering, and physics than in mathematics, and more in mathematics than biology (Matskewich & Cheryan, 2016). Among female undergraduates in physics—but not chemistry—at several U.S. universities, more experiences of stereotype threat lead to lower intentions to pursue a science career (Deemer et al., 2014). Negative stereotypes about women's abilities thus appear to be more problematic in computer science, engineering, and physics than in biology, chemistry, and mathematics.

Influence on gender disparities in participation. Though most research on stereotype threat has focused on performance (e.g., Good, Aronson, & Harder, 2008; P. R. Jones, 2011; J. L. Smith & White, 2002), stereotype threat has also been shown to prevent women from being interested in fields in which they feel negatively stereotyped (J. L. Smith et al., 2007). When stereotypes about women's abilities are salient, female but not male undergraduates show lower belonging and interest in quantitative (e.g., computer science, engineering, mathematics) fields (Good et al.,

2012; J. L. Smith et al., 2007). A national longitudinal study of college students showed that experiences of stereotype threat among women made them more likely to leave science, mathematics, and engineering majors (Beasley & Fischer, 2012). Negative stereotypes can bias women's assessments of their skills (Correll, 2001) and cause women to question their sense of belonging in STEM (Good et al., 2012). For African American and Latino women, the burden of negative stereotypes may be especially imposing, as they are doubly stereotyped on the basis of race as well as gender (Ong et al., 2011).

Perceptions of gender bias and discrimination. Women's perceptions about whether they will encounter gender bias and discrimination in certain fields may influence how likely they are to express an interest in those fields.

Variability within STEM. Women in computer science and engineering programs believe that male and female students are treated differently (Heyman, Martyna, & Bhatia, 2002) and perceive the climate in these majors to be less welcoming and supportive than do men (Morris & Daniel, 2008). Female undergraduates in mathematics, science, and engineering anticipate encountering more discrimination in their careers than women in the arts, humanities, and social sciences (J. R. Steele, James, & Barnett, 2002). Undergraduate women in computer science, engineering, physical sciences, and mathematics report encountering more gender bias than undergraduate women in biological sciences (Robnett, 2015). The same pattern is observed among women in graduate school, but not by high school girls who intend to major in these fields, suggesting that bias in the social environment becomes more apparent to women once they enter a field (Robnett, 2015). However, because mathematics was analyzed together with computer science, engineering, and physics in these studies, it is not clear whether perceptions of gender bias and discrimination correspond to current patterns of variability in gender participation in STEM.

Influence on gender disparities in participation. Women see gender bias and discrimination resulting from negative stereotypes as a potential hurdle to their success in science and mathematics (Ferreira, 2003; J. R. Steele et al., 2002). Female undergraduates in STEM who perceive that others hold negative stereotypes about women's abilities feel a lower sense of belonging in their STEM courses over time (Ahlqvist et al., 2013; Good et al., 2012). The evidence thus suggests that perceiving a biased social environment is a deterrent for women.

Summary. Negative stereotypes about women's abilities meet both criteria for explaining variability within STEM fields. Evidence suggests that fields with the lowest proportion of women evoke more stereotype threat than those that have proportionally more women (Matskewich & Cheryan, 2016; Murphy et al., 2007). More work is needed comparing computer science, engineering, and physics with mathematics to determine whether perceptions of bias and discrimination can explain women's greater representation in mathematics than in computer science, engineering, and physics.

Lack of Role Models

Role models are people who have attained success in a particular domain and can be emulated (Lockwood & Kunda, 1997). Below we review two characteristics of role models that have been

theorized to influence women's interest in STEM: gender and relatability.

Lack of female role models. Much of the research on role models in STEM has focused on the question of how important it is for women to have female role models.

Variability within STEM. Because of women's existing underrepresentation in computer science, engineering, and physics, there are fewer potential female role models in these fields than in biology, chemistry, and mathematics. For instance, slightly less than half of high school computer science teachers (47%: Computer Science Teachers Association, n.d.) and 37% of physics teachers (White & Tyler, 2014) are women. However, the majority of high school teachers in biology (62%; Lyons, 2013), chemistry (54%; P. S. Smith, 2013), and mathematics (57%; National Center for Education Statistics, 2013) are women. Women's employment in STEM fields mirrors patterns of underrepresentation in STEM education: In 2010, women made up nearly half of all employed biological scientists in the U.S., 46% of mathematical scientists, 36% of chemists, 23% of computer and information scientists, 16% of physicists, and 13% of engineers (National Science Foundation, 2014d).

Influence on gender disparities in participation. Women and minority undergraduates are more likely to persist in STEM majors in departments with higher numbers of female and minority graduate students (Griffith, 2010). Enrollment in high school physics classes is less male-dominated in school districts where more women are employed in technological, mathematical, architectural, and engineering fields, potentially because there are more women to serve as role models outside of the classroom (Riegle-Crumb & Moore, 2014). Interventions using female role models or mentors to increase girls' interest and participation have been met with some success (Weisgram & Bigler, 2006), but many of them have used no exposure to role models as a control and thus not identified whether male role models would be just as successful in improving outcomes.

Having female role models is not necessarily a silver bullet. Studies on effects of female faculty and teachers yield inconsistent results. In a sample of five high schools, the percentage of female science teachers was unrelated to girls' interest in science-related majors (Gilmartin, Denson, Li, Bryant, & Aschbacher, 2007). Mathematics departments with more female faculty tend to have more female undergraduates (Sharpe & Sonnert, 1999; see also Sonnert, Fox, & Adkins, 2007). However, this relationship is not linear. When the percentage of female faculty is below 10%, small increases lead to large increases in the percentage of women in the major, but this trend levels off between 10 and 15%. Sharpe and Sonnert suggest that critical mass may be achieved around 15%. Once this threshold is reached, female role models may be visible enough that additional increase in the proportion of female faculty has a less marked effect.

A study of 12 public universities in Ohio found that women who have a female professor for introductory courses in mathematics and statistics are more likely to take further classes in the field than women who have a male professor, but the reverse pattern is observed for biology and physics courses (Bettinger & Long, 2005). Effects of female instructors on women's participation may be different for students at different ability levels. Among public university students in Ohio, the more female professors women have for their STEM classes, the less likely they are to persist in

STEM majors, but this negative relationship is only present for women with ACT scores below the 75th percentile (Price, 2010). Because it was correlational and lacked random assignment, this study cannot rule out the possibility that women who are already less likely to persist in STEM for other reasons tend to choose classes taught by female professors. Another large study of over 9,000 students at the U.S. Air Force Academy took advantage of the fact that students are randomly assigned to professors for many required courses and that placement exam data is available for all students, allowing researchers to control for initial performance. Having a female professor in chemistry, physics, or mathematics increases the likelihood that women with high SAT math scores (i.e., above the median) major in mathematics, science, or engineering, but does not have an influence on women with lower SAT math scores (Carrell, Page, & West, 2010).

Lack of relatable role models. Relatable role models are those with whom students feel a sense of connection, similarity, and identification (Lockwood & Kunda, 1997). Gender-matching may be one component that increases relatability, but there are other characteristics as well.

Variability within STEM. We could find no work examining whether women are exposed to a lower proportion of relatable role models in computer science, engineering, and physics than in biology, chemistry, and mathematics. However, students take fewer courses in computer science, engineering, and physics than biology, chemistry, and mathematics in high school, and this gap is wider for girls than boys (Nord et al., 2011). Thus, even if the proportion of relatable role models is the same in the two sets of fields, it may be more difficult for girls to find relatable role models among their teachers in computer science, engineering, and physics than in biology, chemistry, and mathematics.

Influence on gender disparities in participation. Girls' aspirations are influenced by role models with whom they relate. Female engineering students who read brief biographies of female engineers and strongly identify with these role models are more likely to report wanting to pursue engineering careers than women who do not identify with them as strongly (Stout, Dasgupta, Hunsinger, & McManus, 2011). Women enrolled in chemistry and engineering courses are more interested in science careers when they identify with their instructors and see them as role models, and this is true regardless of instructor gender (Young, Rudman, Buettner, & McLean, 2013).

One determinant known to shape how similar women feel to role models in computer science is the extent to which role models fit current stereotypes. Women report feeling more similar to role models who do not fit computer science stereotypes than those who do (Cheryan, Drury, et al., 2013; Cheryan, Siy et al., 2011). Female undergraduates who interact with an upper-level computer science major who does not fit current computer science stereotypes (e.g., hobbies include playing sports) are more interested in majoring in computer science than women who interact with a stereotypical computer science major (e.g., hobbies include playing video games) regardless of role model gender (Cheryan, Drury, et al., 2013).

Summary. Patterns of existing underrepresentation mean that there is a greater scarcity of potential female role models in computing, engineering, and physics than in biology, chemistry, and mathematics. Although women tend to report that having a role model matched on gender is important to them, this match

does not always correspond to increased interest (Cheryan, Drury, et al., 2013; Drury, Siy, & Cheryan, 2011; Gilmartin et al., 2007). Role models who do not fit current masculine stereotypes of computer science and are relatable to women are able to increase women's interest even if these role models are male (Cheryan, Drury, et al., 2013; Cheryan, Siy et al., 2011). However, the fact that there are few women in prominent positions in STEM fields contributes to the perception of a culture that is more welcoming to men than women (Young et al., 2013). We include lack of female role models as a factor in our model because some studies have shown that a lack of female role models contributes to gender disparities in interest for some women, with the caveat that more research is needed on whether the lack of female role models, the lack of relatable role models, or both contribute to current gendered patterns in STEM participation.

Insufficient Early Experience

The second overarching factor in our model that explains why there are greater gender disparities in some STEM fields is insufficient early (i.e., precollege) experience in computer science, engineering, and physics than in biology, chemistry, and mathematics. There are three components of insufficient early experience discussed below. First, there are fewer course offerings in some STEM fields than others. Second, students' have more freedom to decide which courses to take in some STEM fields than others. Third, there are gender gaps in early experience in some STEM fields but not others.

Few Course Offerings

Educational policy and course requirements play a significant role in shaping the early (i.e., precollege) course offerings that students have in STEM. In U.S. high schools, some STEM classes are required whereas others are typically not offered, depending on state and school requirements and resources (Zinth, 2007).

Variability within STEM. Courses in computer science, engineering, and physics are less likely to be offered in most U.S. high schools than courses in biology, chemistry, and mathematics. Three out of four U.S. elementary, middle, and high school principals report that their school does not provide opportunities for students to learn computer programming (Google & Gallup, 2015b). A survey of seventh through twelfth grade students found that 58% report having a computer science course in their school, though it is unclear how many of these courses teach programming as opposed to other topics (e.g., web design). African American and Latino students and students from poorer backgrounds are even less likely than White students and students with higher household incomes to report that computer science is offered in their school (Google & Gallup, 2015b). Physics is also not ubiquitous in U.S. high schools. In the 2011 through 2012 school year, 63% of U.S. public high schools offered a physics course (United States Departments of Education, 2014). The number of U.S. schools offering biology, chemistry, and mathematics in high school is significantly higher. Most public schools in the U.S. offer biology (87%), chemistry (75%), and mathematics (89% offer Algebra I, 81% offer Algebra II, 85% offer Geometry, though only 50% offer Calculus; United States Departments of Education, 2014). Differences in course offerings thus correspond to current patterns of gender gaps in STEM participation.

Influence on gender disparities in participation. The gender gap in interest in STEM is smaller among high school seniors who attend schools with stronger math and science curricula, and this relationship remains after controlling for school variables such as dropout rate, teacher-student ratio, and proportion of students who go to college (Legewie & DiPrete, 2014). Seventh, eighth, and ninth grade girls who express a strong interest in science and engineering careers are more likely to have participated in school science experiences (e.g., enrichment classes, science club) before seventh grade than those who do not express such interest (Ing, Aschbacher, & Tsai, 2014). Across many nations, greater gender equity in access to formal education is associated with smaller gender differences in motivation to learn mathematics (Else-Quest, Hyde, & Linn, 2010). Fewer course offerings thus predict greater gender gaps in STEM fields.

Summary. Variability in course offerings can help to explain current patterns in gender participation across STEM fields. Biology, chemistry, and mathematics are widely offered in U.S. high schools whereas courses in computer science, engineering, and physics are less likely to be offered (Zinth, 2007). Greater access to STEM courses predicts reduced gender disparities when comparing across U.S. schools and cross-nationally. However, access to courses has not been examined separately from the next factor (freedom to choose courses). More work is needed on whether improving access without changing course requirements will result in reduced gender disparities.

Freedom to Choose Courses

Even when high schools offer computer science, engineering, and physics classes, many students in the U.S. will not take these classes because of the freedom they have to opt out of them.

Variability within STEM. State and school requirements shape which STEM courses are mandatory and which are optional (Zinth, 2007). Of STEM disciplines, mathematics courses are most likely to be required in U.S. high schools, with most states mandating Algebra I/II and Geometry. Biology is the next most common high school requirement, with more than 40% of states mandating that high school students take at least one biology or life science course before graduating. A handful of states require chemistry and even fewer require physics. Instead, many states require that students take one course in either physics or chemistry. No states require students to learn computer programming or engineering (Zinth, 2007).

As a result of the lack of offerings and the flexibility granted to students to choose coursework, fewer high school students take computer science, engineering, and physics courses than biology, chemistry, and mathematics courses. In 2009, 39% of high school graduates had taken a physics course, 19% had taken a computer science course, and 3% had taken an engineering course (Nord et al., 2011). In a nationally representative sample of seventh through twelfth grade students, 57% of boys and 49% of girls reported having learned any computer science, and Latino students were less likely to report having learned computer science than White and African American students (Google & Gallup, 2015a). In contrast, most high school graduates in both public and private schools completed at least one course in mathematics (100%), biology (96%), and chemistry (70%; National Center for Education Statistics, 2012). Fields with the most freedom to choose

coursework in high school are fields with greatest gender disparities in college.

Influence on gender disparities in participation. Because STEM requirements vary across states and countries, they provide a natural experiment for effects of course requirements on gender participation in STEM. Students who live in states with more high school math and science requirements take on average more math and science courses than those in states with fewer requirements, which in turn predicts greater likelihood of majoring in a STEM field, even after controlling for factors such as family income, performance, and eighth grade math and science interest (Federman, 2007). A simulation showed that if all states increased their math and science requirements by one year, there would be a greater increase in the proportion of women (21%) than men (13%) who majored in STEM in college (Federman, 2007). Having greater STEM course requirements may give girls opportunities to learn about a field instead of relying on stereotypes about what fields are like and how successful they would be in them.

Looking at cross-national and cross-cultural comparisons also illuminates the role of educational choice in shaping gender disparities. Countries in which girls and boys have less choice of coursework and greater STEM requirements (e.g., Turkey, Ireland, Korea) have fewer gender disparities in college than countries that give students considerable freedom to choose coursework in high school and college (Charles & Bradley, 2006, 2009). Gender disparities in interest in computer science, engineering, and physics are bigger among White students than they are among Asian Americans (National Science Foundation, 2014b). White American culture encourages values such as personal choice and self-expression, whereas Asian cultures are more oriented toward interdependent values, such as adjusting to one's environment and being family oriented (Markus & Conner, 2014). Asian Americans may be more likely to choose careers based on what might be financially practical or desirable for them and their families whereas White students may be more likely to choose careers that fit with how they see themselves. Using self-expression goals to guide career choices creates gender disparities because of a reliable gender difference in the extent to which men and women see themselves as being masculine or feminine (Cech, 2013; Zell, Krizan, & Teeter, 2015). Freedom of choice may thus enable gendered preferences to reveal themselves (Charles & Bradley, 2009).

Summary. The greater freedom that students have to choose computer science, engineering, and physics than biology, chemistry, and mathematics may contribute to current patterns of gender disparities in STEM fields. Providing students less choice to opt out of STEM classes can help offset cultural forces that are dissuading women from these learning opportunities. Does that mean that making computer science, engineering, and physics mandatory in U.S. high schools will eliminate gender gaps in participation later in the educational pathway? Mandatory experience has the potential to moderate several aspects of the masculine culture of these fields. Girls' stereotypes about what the people are like and what the work entails can be overturned to the extent that the course and classroom environment promote a less masculine image of the field (Cheryan et al., 2009). Seeing other girls and women in their courses helps defend against stereotype threat (Murphy et al., 2007; Stout et al., 2011) and may weaken associations between STEM and males (D. I. Miller, Eagly, & Linn,

2015). Such experience also exposes girls to multiple role models in the field (e.g., their teachers), maximizing their chances of finding someone relatable and inspiring (Lockwood & Kunda, 1997). Finally, some girls who may have been uninterested in a field may learn by taking courses in the topic that they enjoy and perform well in it (Brainard & Carlin, 1998). The extensive early experience that students in the U.S. get with math throughout their education may explain why math has a less masculine culture (e.g., less masculine stereotypes, more female role models) than computer science, engineering, and physics.

However, ensuring students get early experiences with computer science, engineering, and physics will not be enough to reduce gender gaps. Efforts to offer both women and men STEM experience can increase interest for both groups (Lopatto, 2007) but do little to diminish gender gaps in participation (Ceci & Papierno, 2005; Pollock, Finkelstein, & Kost, 2007) if broader cultural factors, such as the masculine cultures of these fields, are not addressed (see Lang, Fisher, Craig, & Forgasz, 2015, for a study in Australian middle and high schools). To counteract the masculine culture, courses must signal to girls and boys equally that they belong in the field. If learning opportunities reinforce rather than counteract the current masculine culture of these fields, then providing girls with more experience may *widen* rather than lessen gender gaps.

Gender Gaps in Early Educational Experiences

The flexibility that students have to choose whether to learn computer science, physics, and engineering, combined with these fields being currently more appealing to boys than girls, has created gender gaps in high school course-taking and extracurricular activities in the U.S.

Variability within STEM. High school girls are significantly less likely than boys to take courses in computer programming (Barron, 2004; Nord et al., 2011), engineering (Nord et al., 2011), and physics (Hazari, Sonnert, Sadler, & Shanahan, 2010; Nord et al., 2011). College women in introductory computer science (Sackrowitz & Parelius, 1996) and introductory physics (Kost-Smith, Pollock, & Finkelstein, 2010; Moses, Howe, & Niesz, 1999) courses report having taken fewer prior computer science and physics courses than their male peers. These gender gaps in previous educational experience may help explain why women tend to score lower than men on tests in introductory college computer science and physics classes (Kost-Smith et al., 2010).

Boys do not outnumber girls in high school biology, chemistry, and math courses. In fact, high school girls take slightly more biology and chemistry courses than do boys (Burkam, Lee, & Smerdon, 1997; Schreuders, Mannon, & Rutherford, 2009). In 2009, 96% of female high school graduates took biology compared with 95% of boys (National Center for Education Statistics, 2012), and 50% of female high school graduates took advanced biology compared with 39% of boys (Nord et al., 2011). High school girls were also significantly more likely (72%) than boys (67%) to take chemistry (Nord et al., 2011). High school girls also take no fewer, and sometimes even more, math courses than boys do (Long, Iatarola, & Conger, 2009; Nord et al., 2011; Schreuders et al., 2009). Girls are significantly more likely to take Algebra II and Precalculus than their male peers and are equally likely as boys to take Calculus (Nord et al., 2011). However, a study of high school

students in Florida found that while girls are more likely than boys to take some math courses (e.g., trigonometry), they are less likely than boys to take the most advanced math courses (e.g., advanced calculus; Tyson, Lee, Borman, & Hanson, 2007).

Even when they are in the same classes, girls and boys may get differing educational experiences, and these differences may be larger in physics than in biology (Kahle, Matyas, & Cho, 1985). In high school physics courses, girls spend more time reading the textbook and working on daily homework, whereas boys spend more time on physics-related projects and attempts to understand concepts (Hazari et al., 2010). College women taking introductory physics begin with less expert-like physics attitudes (i.e., less focus on conceptual understanding) than college men (Kost-Smith et al., 2010).

Extracurricular activities can be a significant source of experience, especially when students are unable to get experience through courses. High school girls report less past programming experience, lower likelihood of having taken apart a computer, and fewer hours of personal computer use than do high school boys (Barron, 2004). Boys learn about physics more from hobbies, media, books, classes, and employment than do girls (Hazari et al., 2010), and they report more prior experiences with electric toys, fuses, and pulleys (M. G. Jones, Howe, & Rua, 2000). Boys spend more time than girls on computer science and physical science exhibits at science museums whereas girls spend more time than boys on human body exhibits (Greenfield, 1995b). Boys are more likely than girls to choose science fair projects related to computer science, earth science, and physical sciences (Greenfield, 1995a).

Influence on gender disparities in participation. We could find no work examining whether closing gender gaps in high school course-taking would significantly reduce gender gaps in choice of major or career. However, gender gaps in high school course-taking and extracurricular activities are important because of what happens when students get to college. College students report that some introductory courses are oriented toward students with greater previous experience (Bunderson & Christensen, 1995). Men are at an advantage in these classes because they typically enter with more computer science, engineering, and physics experience than women do (Sackrowitz & Parelius, 1996). As a result, women in these classes may feel that they are already behind some of their male peers. Some computer science departments have tried to remedy this by having two introductory courses for incoming students, one for less experienced students and the other for more experienced students (Klawe, 2015).

One common intervention to increase girls' experience with these fields is to have girls participate in STEM summer camps and afterschool programs. These programs may reduce gender gaps in preparation and allow girls to enter computer science, engineering, and physics courses with the same level of preparation as their male peers. These programs may also teach girls that they like a subject they had not tried previously. However, if girls continue to believe that the culture of the broader field is masculine, such programs may not successfully draw more girls into these fields, regardless of how much girls like the programs. There is some evidence that activities that include both girls and boys might be more effective for girls than those that exclusively target girls (Legewie & DiPrete, 2014; Patitsas,

Craig, & Easterbrook, 2015), perhaps because these programs give girls a more realistic sense of what the field will be like. According to our model, the most successful interventions to draw girls into computer science, engineering, and physics must counteract the masculine culture of the fields so that girls feel a sense of belonging in them. Interventions to improve STEM experience can also backfire for students of color if these interventions do not address the multiple barriers that can preclude their sense of belonging (Ong et al., 2011).

Summary. Lack of course offerings and the freedom to choose courses meet both criteria for explaining current patterns of variability in STEM fields. Girls are also less likely to get early computer science, engineering, and physics experiences than boys, though there is a dearth of evidence on whether this gender disparity in early experience contributes to the gaps we see in choice of major and careers, or whether both patterns are the result of other causes (e.g., masculine culture of the fields). For this reason, we include course offerings and freedom to choose coursework but exclude gender gaps in early experiences from our model, though we believe that gender gaps in early experience may contribute to women feeling less prepared in introductory computer science, engineering, and physics courses.

Gender Gaps in Self-Efficacy

The third factor in our model is gender gaps in self-efficacy. Self-efficacy is the belief that one has the capacity to be successful at a particular task (Bandura, 1994). Self-views or self-assessments are students' perceptions of their abilities and skills in STEM (Cech et al., 2011; Correll, 2001; Sax, 1994a). These constructs have been measured a variety of ways, including students' ratings of their abilities compared with their peers (Sax, 1994a), confidence in their own ability to complete STEM-related tasks or a program of study (Cech et al., 2011; Concannon & Barrow, 2009), and anticipated success in a field (Cheryan, Siy et al., 2011; Litzler, Samuelson, & Lorah, 2014).

Variability Within STEM

Among high school and undergraduate students, women report lower self-efficacy and self-views than men in computer science (Cheryan & Plaut, 2010; Irani, 2004; Rosson, Carroll, & Sinha, 2011) and physics (Cavallo, Potter, & Rozman, 2004; Sawtelle, Brewe, & Kramer, 2012). Some studies have found similar results in engineering, with undergraduate women in engineering reporting lower self-efficacy than their male peers, even though women are obtaining higher grades in these courses than men (Huang & Brainard, 2001). Other studies have shown female and male undergraduates in engineering reporting similar ability to succeed in their programs (Concannon & Barrow, 2009, 2012; Lent et al., 2005). Still others found female engineering undergraduates reporting higher engineering self-efficacy than male engineering undergraduates, measured as a combination of perceived ability to succeed in engineering courses and abilities in math, science, and engineering (B. D. Jones, Ruff, & Paretti, 2013). Women who select into a competitive engineering program may be no less likely than men to believe they will do well in their courses, but they may still perceive their engineering ability as lower.

Gender gaps in self-efficacy also exist in mathematics (Correll, 2001; Else-Quest et al., 2010; Sax, 1994a, 1994b; Simpkins, Davis-Kean, & Eccles, 2006). In a study of more than 15,000 undergraduates attending nearly 400 four-year colleges and universities, the average woman entering these schools assessed her math ability compared with the average person her age as "average" whereas the average man assessed his as closer to "above average" (Sax, 1994a). Furthermore, nearly one-quarter (24%) of these men rated themselves in the "highest 10%" of math ability while only 11% of women did (Sax, 1994a). Gender differences in self-assessments persist even after controlling for actual math performance (Correll, 2001; Ross, Scott, & Bruce, 2012; Sax, 1994b). In other words, even among equally competent males and females, males report their math ability as higher. Gender gaps in math self-assessments have been observed across the pipeline, from elementary school (Fredricks & Eccles, 2002; but see Swiatek, 2004) to college (Correll, 2001; Sax, 1994a). However, gender gaps in math self-efficacy progressively narrow from first through twelfth grade (Fredricks & Eccles, 2002), but then increase during college, especially at selective universities (Sax, 1994a).

Some studies find that high school girls rate themselves equally good at science as high school boys (Else-Quest et al., 2013), whereas others find that girls and women have lower science self-efficacy than their male peers (Ehrlinger & Dunning, 2003; Louis & Mistele, 2012; Simpkins, Davis-Kean, & Eccles, 2005). A comparison between fields showed the self-efficacy gender gap among a general population of undergraduates is largest in computer science and engineering and smallest in biology, with mathematics in the middle (Matskewich & Cheryan, 2016). Gender gaps in self-efficacy thus appear to largely correspond to patterns of variability in gender participation that we have seen in STEM fields, with the exception of the mixed findings in engineering and no evidence from chemistry.

A study with more than 7,000 engineering students from 21 universities revealed interesting interactions of gender and race on self-efficacy. Although there is a gender gap in self-efficacy between White women and men, Asian American women and men do not differ from each other or from White men after controlling for background variables (e.g., field of study). In addition, African American and Latino men report higher STEM self-efficacy than White men while African American and Latino women do not differ from White men (Litzler, Samuelson, & Lorah, 2014; but see Concannon & Barrow, 2009). Cultural and social factors that encourage self-reliance and the importance of disproving negative academic stereotypes may explain why African American and Latino men have higher self-efficacy scores than White men (Correll, 2001; Litzler et al., 2014). One study with a nationally representative sample of high school sophomores in public and private schools found that African American girls who express more confidence that they would succeed in math have lower odds of being recommended by their teacher for honors or advanced courses than African American girls who express less confidence (Campbell, 2012). These findings suggest that high self-efficacy may be insufficient to encourage women into STEM without remedying other factors (e.g., discrimination, inadequate academic opportunities).

Influence on Gender Disparities in Participation

Controlling for gender gaps in self-efficacy in the U.S. reduces gender gaps in both recruitment (Correll, 2001; Ehrlinger & Dunning, 2003) and retention (Ackerman, Kanfer, & Beier, 2013) in science and mathematics. These effects remain even when controlling for actual performance (Correll, 2001). However, across 50 countries, controlling for gender gaps in science self-efficacy does not reduce gender disparities in plans to pursue computer science, engineering, and mathematics or biology, agriculture, and health (Sikora & Pokropek, 2012).

Some work has found a positive relationship between computer science self-efficacy and interest in pursuing computer science (Lent et al., 2011; Rosson et al., 2011) whereas other work has not (Cech et al., 2011; Irani, 2004; Wilson, 2002), especially when other factors such as enjoyment are taken into account (Riegle-Crumb, Moore, & Ramos-Wada, 2011). Controlling for computer science self-efficacy, measured as confidence in one's computer programming ability, coursework, and personal uses, reduces the gender gap in interest in taking a future computer science course among undergraduates (Miura, 1987). However, this study did not control for prior experience (e.g., number of computer science courses), making it difficult to know whether differences in self-efficacy were independently predicting interest, above and beyond differences in experience. A study that controlled for prior programming and quantitative experience did not show a significant relationship between self-efficacy and interest (Ogletree & Williams, 1990). Engineering students who report greater confidence in their ability to advance and be successful in engineering are more likely to persist in engineering three years later (Cech et al., 2011).

Researchers have also looked at the relationship between math self-efficacy and choice of computer science, engineering, and physics. Gender gaps in math self-efficacy partially account for gender gaps in who majors in computer science, engineering, and physics (Perez-Felkner et al., 2012; Sax, Kanny, Riggers-Piehl, Whang, & Paulson, 2015). However, math self-efficacy has become a weaker predictor of who chooses a computer science major over the past four decades (Sax et al., 2015).

Fields in which women are stereotyped negatively are more likely to have gender gaps in self-efficacy than fields in which women are not stereotyped negatively (Correll, 2001). In an experiment that manipulated negative stereotypes, women were told either that men tend to outperform women on a fabricated measure of "contrast sensitivity" or told that there are no gender differences in contrast sensitivity. Women who were led to believe that men on average have better contrast sensitivity rate themselves as having lower contrast sensitivity than men and report lower interest in future graduate programs and careers that supposedly require high contrast sensitivity (Correll, 2004). The fact that women perceive stronger negative stereotypes in computer science, engineering, and physics than biology (Matskewich & Cheryan, 2016) may help to explain why gender gaps in self-efficacy are larger in these fields. Women may also face social pressure to publicly downplay their interest and achievements in male-dominated fields (Daubman, Heatherington, & Ahn, 1992; Rudman, 1998).

We could find no experimental work that tested whether increasing women's self-efficacy, without also affecting other factors such as experience, changed women's STEM interest or

participation. However, work outside of STEM has found that increasing students' self-efficacy without providing more experience (i.e., by giving them high or low scores as anchors) increases persistence on problem-solving tasks (Cervone & Peake, 1986), suggesting that increasing women's STEM self-efficacy may similarly increase their persistence with STEM tasks.

Summary

There is mixed evidence that the gender gaps in self-efficacy factor qualifies for our model. Computer science, engineering, physics, and math have gender gaps in self-efficacy, with at least one study showing smaller self-efficacy gaps in math than in computer science and engineering (but others showing no gender gaps in engineering). Gender gaps in self-efficacy predict gender gaps in interest in some studies but not others. We include this factor in our model because of existing evidence supporting both criteria, but more work is needed to fully identify the contribution of this factor to current patterns of gender disparities.

One consideration is whether the goal should be for women's self-views to reach the height of men's self-views, or whether it is better to consider the benefits that go along with being modest (or accurate) about one's own skills. Indeed, women's views may be largely accurate while it is men who may be overestimating their abilities (Bench, Lench, Liew, Miner, & Flores, 2015; Hügelschäfer & Achtziger, 2014; but see Sax, 1994b). The most useful interventions may be ones that teach people (both men and women) how to more accurately assess their ability and when confidence is useful and warranted.

Factors That Are Less Likely to Explain Current Variability in Gender Participation

Next we turn to reviewing factors that do not appear to explain why women are more underrepresented in computer science, engineering, and physics than in biology, chemistry, and mathematics. Both formal discrimination and math abilities and performance do not meet at least one of the criteria for explaining current patterns of gender disparities in STEM participation (see Table 2).

Formal Discrimination

Gender discrimination occurs when individuals are treated differently on the basis of their gender,[8] regardless of whether this treatment results from hostile intent (Greenwald & Pettigrew, 2014). Discrimination can manifest early in life as differential treatment and encouragement from parents, teachers, and others. Discrimination can result in more direct denials of opportunities later on in their educational path and in the social marginalization of women who enter stereotypically masculine domains.

Variability within STEM. We found no research examining whether biases by parents, teachers, and counselors are stronger in computer science, engineering, and physics than biology, chemistry, and mathematics. Later in the educational path, though discrimination against women is typically more prominent in jobs that are traditionally male-dominated than those that are female-dominated or gender-balanced (Koch, D'Mello, & Sackett, 2015), formal discrimination against women in college has been observed in a range of STEM fields, with little evidence that it is worse in

male-dominated STEM fields. Women are less likely than men with identical resumes to be hired for hypothetical biology, chemistry, and physics lab manager positions, and biology, chemistry, and physics faculty do not significantly differ in this tendency (Moss-Racusin et al., 2012). Professors in the natural sciences, physical sciences, and mathematics are less likely to respond to email requests to discuss research opportunities from White women than White men whereas professors in computer science, engineering, and life science do not show this bias. However, computer science and engineering faculty show significant bias against African American females, African American males, Chinese females, Chinese males, Indian males, and Latino males compared with White males. Professors in the life sciences show significant bias against Chinese females, Indian males, Indian females, and Latino males compared with White males (Milkman, Akinola, & Chugh, 2015). Disparate treatment is thus apparent in a range of STEM fields, and fields with the least underrepresentation of women appear to discriminate against women just as much as those with greater underrepresentation.

Highly qualified female applicants are preferred over equally qualified male applicants by faculty for hypothetical tenure-track assistant professorships in biology and engineering, and engineering faculty are as likely to prefer female over male applicants as biology faculty (W. M. Williams & Ceci, 2015). Bias might be attenuated with highly qualified candidates because it reduces the ambiguity of whether a candidate will be successful at the job (Koch et al., 2015; Steinpreis, Anders, & Ritzke, 1999), and highly qualified women may seem more impressive because of lower expectations stemming from negative stereotypes about women's competence (Biernat, 2005).

Women in male-dominated fields also risk backlash, or negative social and economic repercussions for violating gender stereotypes (Eagly & Karau, 2002; Rudman & Phelan, 2008), making advancement more difficult. A meta-analysis found that women who express dominance are perceived as less likable ($d = .19$) and less hireable ($d = .58$) than men who express dominance (M. J. Williams & Tiedens, 2016). Although we could find no research comparing likelihood of backlash across different STEM fields, the risk of backlash may be highest in the most male-dominated fields (Rudman, 1998).

Influence on gender disparities in participation. Discrimination can discourage girls' and women's participation in STEM. Sixth-grade girls whose mothers believe that they are less likely to succeed in math-related careers are significantly less likely to choose physical science or computing careers as young adults whereas mothers' perceptions of their son's abilities have no relationship to their choice of these careers (Bleeker & Jacobs, 2004). Fathers in Canada with stronger implicit associations linking women with home and men with careers are more likely to have daughters who have less interest in stereotypically masculine occupations (Croft, Schmader, Block, & Baron, 2014). Among high school students in Israel taking computer science, 61% of the students in the Arab sector are girls compared with only 28% of

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[8] This section focuses on formal discrimination, or whether women are denied more STEM opportunities than men (King, Mendoza, Madera, Hebl, & Knight, 2006). For work that examines interpersonal discrimination, see the perceptions of gender bias and discrimination section.

students in the Jewish sector. Courses in both sectors are coed and have the same curriculum and syllabus, but girls in the Arab sector report greater encouragement from parents, siblings, friends, and teachers to take computer science than girls in the Jewish sector (Eidelman & Hazzan, 2005; Frieze, Hazzan, Blum, & Dias, 2006). Later in the pipeline, discrimination can result in fewer STEM opportunities for women than men (e.g., Reuben, Sapienza, & Zingales, 2014). Small differences in treatment can accumulate and result in large differences in outcomes between women and men (Valian, 1998).

Summary. Though some have argued that gender discrimination is not a primary cause of women's continued underrepresentation in STEM (Ceci et al., 2014; Ceci & Williams, 2010), the evidence reviewed above shows that it creates obstacles for women that their White male peers do not face. These obstacles are present across STEM fields and evidence to date suggests that they are not any less problematic in fields in which women have achieved greater representation, such as biology and chemistry. Discrimination against girls and women is apparent across a range of STEM fields, even those fields in which women are better represented.

Math Ability and Performance

The question of whether there are gender differences in math ability is hotly debated (e.g., Benbow & Stanley, 1982; Hyde, Lindberg, Linn, Ellis, & Williams, 2008; Spelke, 2005) in part because there is no pure measure of intrinsic ability. Researchers use performance on math tests and in math courses as a proxy for ability, though test performance is shaped by situational factors, such as academic preparation and the presence of negative stereotypes (C. M. Steele & Aronson, 1995). In order for math ability and performance to explain the greater underrepresentation of women in computer science, engineering, and physics, people in computer science, engineering, and physics must have higher math ability than people in biology, chemistry, and mathematics, and women must perform worse than men in mathematics.

Variability within STEM. Computer science, engineering, and physics do not draw from a quantitatively superior pool than biology, chemistry, and mathematics. The average math GRE score is almost identical in computer science (157), engineering (159), and physics (161) as in biology (154), chemistry (158), and mathematics (162; Educational Testing Service, 2014; see College Board, 2014, for SAT information). Additionally, there is no field that contains more math (and has a higher average math GRE score) than mathematics, a field that is significantly more gender balanced than computer science, engineering, and physics. Differences in math performance therefore cannot explain why mathematics is more gender balanced than computer science, engineering, and physics.

Influence on gender disparities in participation. Several meta-analyses find that gender differences on national math exams among U.S. elementary, middle, and high school students are minimal ($d < .10$) or do not exist (Else-Quest et al., 2010; Lachance & Mazzocco, 2006; Lindberg, Hyde, Petersen, & Linn, 2010; Scafidi & Bui, 2010; but see Fryer & Levitt, 2010; Sohn, 2012). In fact, girls tend to outperform boys on math tests in elementary school (Gibbs, 2010). Throughout schooling, women tend to receive higher grades in computer science, physics, and math courses (Downey & Vogt Yuan, 2005; Halpern et al., 2007; Hazari, Sadler, & Tai, 2008). However, on high-stakes high school math and science tests (e.g., math SAT, science reasoning ACT), boys obtain slightly higher mean scores than girls (Buddin, 2014; College Board, 2013; Fryer & Levitt, 2010). Multiple factors may explain why girls often outperform boys in courses but sometimes perform worse than boys on tests, including the salience of negative stereotypes in high-stakes testing situations (Spencer et al., 1999). Indeed, college admissions tests underestimate the future performance of girls and overestimate the future performance of boys (Fischer, Schult, & Hell, 2013; Spelke, 2005; Walton & Spencer, 2009). A meta-analysis based on the mean of the residuals obtained from regressions examining the relationship between admissions test scores and future grades reveals positive scores for women (i.e., predicted value is less than observed value; $d = .14$) and negative scores for men ($d = -.16$; Fischer et al., 2013). Taken together, examining average test scores and grades reveals little evidence for boys being, on average, better at mathematics than girls.

Though there are few differences in mean math performance between boys and girls, boys are more likely than girls to be represented among the top math and science scorers (Ellison & Swanson, 2010; Hyde & Linn, 2006; Sohn, 2012; Wai, Cacchio, Putallaz, & Makel, 2010), and the gender gap among top performers is bigger in math than science (Olszewski-Kubilius & Lee, 2011). However, more women have become top math performers in recent decades (Halpern et al., 2007; Hyde & Mertz, 2009). In some countries (e.g., Bahrain, Estonia), there is no gender gap in national math test performance (Else-Quest et al., 2010; Fryer & Levitt, 2010).

Some attest that the overrepresentation of boys among the highest math scorers may explain why women are underrepresented in computer science, engineering, and physics (Wai et al., 2010). There are two reasons to doubt the validity of this assertion. First, cross-nationally, the correlation between girls' performance in mathematics and their aspirations for jobs involving mathematics is negligible (Charles & Bradley, 2006). In fact, girls in the U.S. with the highest math ability in the tenth grade choose social, behavioral, clinical, and health majors over majors in computer science, engineering, physical science, and mathematics (Perez-Felkner et al., 2012; see also Wai, Lubinski, & Benbow, 2009, for similar evidence with spatial performance). Whereas boys who are in the top 1% of math ability between the ages of 12 and 14 are more likely to pursue careers in inorganic sciences and engineering, equally math-talented girls gravitate more to medicine, arts, and biology (Benbow, Lubinski, Shea, & Eftekhari-Sanjani, 2000). Girls with high math ability are more likely to have high verbal scores than similarly math-proficient boys and therefore may have wider options of majors (M. T. Wang et al., 2013). Second, the top-scorers argument does not explain why mathematics—the field with the highest average math GRE scores—is more gender-balanced than computer science, engineering, and physics.

Gender differences in math performance may also interact with race (Martinez & Guzman, 2013; Hyde et al., 2008; but see Scafidi & Bui, 2010 for no evidence of a gender by race interaction). One study found that the gender gap in math performance among high school students exists for Latinos, is smaller for Whites and Asian Americans, and is not present (and is even slightly reversed) for African Americans (Fan, Chen, & Matsumoto, 1997). Issues of

racial equity are particularly important when it comes to STEM learning because performance differences between racial groups are considerably larger than gender differences within racial groups (Fryer & Levitt, 2010; Muller, Stage, & Kinzie, 2001; Walker & Plata, 2000).

Girls and women tend to score lower on tests of mental rotation (one component of spatial reasoning) than boys and men (Ganley & Vasilyeva, 2011; Maeda & Yoon, 2013). However, we could find no work linking gender differences in spatial ability to gender differences in interest or participation. Though there have been several published attempts to improve women's spatial performance (e.g., Casey et al., 2008), we could not find any that demonstrated a statistically significant effect on outcomes such as likelihood of majoring in a STEM field (see D. I. Miller & Halpern, 2013, for an intervention that improved spatial skills but did not affect gender disparities).

A review of 75 studies revealed that math performance is more positively correlated with verbal performance than with spatial performance, and when correlations between spatial and math performance are compared with other correlations, it is "not convincing evidence that spatial skill is well related to mathematical ability" (Friedman, 1995, p. 40; see also Carr, Steiner, Kyser, & Biddlecomb, 2008; Ganley & Vasilyeva, 2011). Recent experiments also find a weak to nonexistent relationship between video game playing, an activity that boys traditionally participate in more than girls (Lucas & Sherry, 2004), and improved cognitive abilities (Unsworth et al., 2015).

Summary. Gender gaps in performance on national math tests have narrowed in the past few decades to the point where they are minimal or nonexistent on national high school math exams. However, there continue to be reliable differences in some populations (e.g., top math performers) and on some tests (e.g., SAT Math). Note that women receive a significantly greater proportion of bachelor's degrees in mathematics (44%) than computer science (18%), engineering (19%), and physics (19%; National Science Foundation, 2014a), demonstrating that women are not underrepresented in all math-intensive fields. Computer science, engineering, and physics are losing out on recruiting large numbers of women who are highly skilled in math (e.g., as evidenced by high SAT math performance) and have the requisite high school background (Iskander, Gore, Furse, & Bergerson, 2013). Girls with the highest math ability are more drawn to the social and health sciences than to computer science, engineering, and physics. This suggests that increasing women's math performance without changing other factors might steer more women into the social and health sciences than into computer science, engineering, and physics.

Other Factors

The factors we reviewed above represent the ones most prominently examined in the empirical social science literature on gender disparities in STEM fields. Here we briefly discuss three other factors that have been proposed and have empirical support but do not have enough evidence to evaluate for our model: (a) labor market and institutional forces, (b) peer support, and (c) attitudes toward STEM.

Labor Market and Institutional Forces

Labor market forces shape who chooses to enter and remain in STEM fields (Fox & Stephan, 2001). Computer science may be particularly prone to shifting labor market forces. Enrollments in college computer science courses increased during periods of growth in the computer industry (e.g., PC revolution, dot-com boom), and it is during subsequent downturns that gender gaps in participation widened (National Science Foundation, 2014a). Computer science departments with faculty who report that their departments are more adaptable to changes in the job market are better at retaining women than computer science departments in which faculty report being less adaptable (Cohoon, 2006). A meta-analysis showed that high school girls have a small but significant preference ($d = .03$) for jobs with greater job security compared with high school boys (Konrad et al., 2000). Women may be more risk-averse than men and consequently more interested in majors that are less competitive and have more stable job prospects (Alon & DiPrete, 2015; Sapienza, Zingales, & Maestripieri, 2009). Women may also be interested in majors that allow for more flexibility of coursework (Mann & DiPrete, 2013).

Peer Support

Students of both genders benefit from having peer support (Buday et al., 2012; Ost, 2010; Robnett & Leaper, 2013; Stake, 2006; Stake & Nickens, 2005). However, peer support may be more important for women than men (Ost, 2010; Riegle-Crumb, 2006) and especially important for women of color (Espinosa, 2011). The relationship between peer persistence and student persistence may be stronger for women in the physical sciences than for women in the life sciences or men in either type of field (Ost, 2010; but see Buday et al., 2012). Computer science departments with more female students retain women at higher rates than computer science departments with fewer female students (Cohoon, 2006).

Having peers who are supportive of students' pursuit of science predicts interest (Leaper, Farkas, & Brown, 2012; Robnett & Leaper, 2013; Stake, 2006) and retention (Crosnoe, Riegle-Crumb, Field, Frank, & Muller, 2008; Espinosa, 2011; Stake & Nickens, 2005). Women of color majoring in STEM who speak to friends about their coursework are more likely to persist in their major (Espinosa, 2011), and girls who perceive greater support from friends are more likely to get involved in extracurricular science activities and aspire to science- or math-related careers (Jacobs, Finken, Griffin, & Wright, 1998). Efforts to foster peer support include creating clubs or groups (e.g., Women in Engineering) to enable women in STEM to meet and provide support to one another. More empirical research is needed to examine whether these clubs and groups are successful in recruiting and retaining women in STEM.

Attitudes Toward STEM

College women are more likely than men to implicitly associate science and mathematics with negative words (e.g., bad) than positive words (e.g., good; Nosek, Banaji, & Greenwald, 2002), and this gender difference has been observed even among students in math-intensive majors (Nosek et al., 2002). Recent efforts have

examined how to change these associations with STEM. College women who are not highly identified with mathematics exhibit more positive implicit attitudes toward mathematics when they are instructed to pull a joystick toward themselves when they see math symbols compared with when they are instructed to push a joystick away from themselves when seeing math symbols (Kawakami, Steele, Cifa, Phills, & Dovidio, 2008). Similarly, when women who are moderately identified with mathematics associate mathematics words with things they like, their motivation to complete math problems 24 hours later increases (Forbes & Schmader, 2010). However, this work does not report whether attitudes vary across STEM fields, and if so, why.

Findings on STEM enjoyment and anxiety have been mixed. Among fourth graders, boys and girls report equal enjoyment of science (Riegle-Crumb et al., 2011). However, by eighth grade, girls report less enjoyment of science than boys do (Riegle-Crumb et al., 2011), and ninth-grade girls report that they like learning about science less than ninth-grade boys do (Riesz, McNabb, Stephen, & Ziomek, 1994). Enjoyment of science predicts aspirations toward a job in science among White female eighth graders even after controlling for science self-efficacy (Riegle-Crumb et al., 2011). Some work on STEM anxiety finds that girls and women have greater math and computer anxiety than boys and men (Udo, Ramsey, Reynolds-Alpert, & Mallow, 2001; Woodard, 2004) while other work finds no differences (Haynes, Mullins, & Stein, 2004). For undergraduate women (but not undergraduate men), math test anxiety positively correlates with math ability, suggesting that the most qualified women may be the most vulnerable (Haynes et al., 2004). However, when math motivation is high, a moderate level of math anxiety is more predictive of higher performance than a lower level of math anxiety (Z. Wang et al., 2015). More research is needed on STEM enjoyment and anxiety to determine whether these factors can explain variability in gender participation within STEM.

What Will Work to Reduce Women's Underrepresentation?

Many current efforts to reduce gender disparities in STEM involve encouraging girls toward fields in which they are already relatively well represented. For instance, parents may purchase chemistry sets or medical kits for girls to encourage them to develop an interest in chemistry and medicine. These efforts are important because they encourage girls to enter fields that were once heavily male-dominated. However, our analysis reveals that computer science, engineering, and physics currently face different and significantly greater challenges than biology, chemistry, and mathematics in eliminating gender disparities in participation among their students. To remedy underrepresentation in the fields that *remain* male-dominated in college, girls will need to be encouraged specifically toward computer science, engineering, and physics.

Looking across the educational pipeline from elementary school to graduate school reveals that the underrepresentation of women in computer science, engineering, and physics begins well before college and is attributable more to a failure to recruit girls into these fields than a failure to convince girls who enter these fields to stay. In fact, computer science, engineering, and physics currently appear to have *less* of a decline in the proportion of women

through the academic pipeline than more gender-balanced fields, such as psychology and biology (Ceci et al., 2014). Although making sure that women are retained in these fields is crucial to remedying underrepresentation, interventions that address the barriers that prevent women from entering them in the first place will likely have the most immediate success in increasing the number of women who obtain degrees in computer science, engineering, and physics.

Our model identifies three factors that explain why there is a lower representation of women in computer science, engineering, and physics than biology, chemistry, and mathematics: masculine cultures, insufficient early experience, and gender gaps in self-efficacy (see Figure 5). The evidence linking masculine cultures to gender disparities in participation is both correlational and experimental, but we were only able to find correlational evidence linking insufficient early experience and gender gaps in self-efficacy to gender disparities in participation. More experimental work is needed on the latter two factors. More work is also needed on how these three factors interact with one another to create and sustain gender disparities. Insufficient early experience on its own may not cause disparities, but disparities occur when a lack of experience is paired with a masculine culture. Mandating early and sustained experience may counteract masculine cultures somewhat by changing stereotypes and exposing students to multiple role models. In addition, self-efficacy gaps are minimal or nonexistent in fields in which women are not stereotyped negatively (Correll, 2001). Culture change may thus be an effective way to eliminate gender gaps in self-efficacy and reduce gender gaps in participation without needing to mandate early experience.

People in technology, government, and education are working intently to make computer science widely offered and mandatory in U.S. schools (e.g., Guynn, 2015; Obama, 2016). Will this effort reduce gender disparities in computer science participation? Our analysis reveals that fields with the least gender differences in participation are the ones that are ubiquitous and mandatory in high school. However, we hasten to add that efforts to give students more experience need to be implemented carefully and thoughtfully. Experiences can backfire—that is, women's underrepresentation could get *worse*—if the culture of those experiences is not taken into account. Experiences can exacerbate gender disparities if they promote gendered ideas about computer science (e.g., masculine stereotypes of the people and the work involved, harmful stereotypes of women), prevent women from encountering support and inspiration (e.g., finding relatable role models), cause women to believe that they will not be successful, or are located within biased institutional practices (e.g., discrimination). The research is clear on what is important: Experiences that provide girls and women with learning opportunities and necessary support as they progress, that diversify current stereotypes of the field, that do not discriminate or devalue women, and that allow women to know that they can achieve success in the field are likely to make the biggest impact.

The research is also clear on what may be less important in reducing gender disparities in participation: Girls already know that science and engineering are important and valuable fields. Reinforcing the importance of these fields to boys and girls may be a useful strategy to recruit more students into STEM but will likely do less to close gender gaps in participation. Moreover, based on current trends, raising the math performance of girls in high school

may result in more women entering the social and health sciences over computer science, engineering, and physics.

In support of our model, computer science departments at Harvey Mudd, Carnegie Mellon, and University of Washington made several changes that resulted in impressive increases in the percentage of female computer science graduates in less than a decade (i.e., less than 10% to 40% at Harvey Mudd and Carnegie Mellon and 15% to 30% at University of Washington; Klawe, 2015; Margolis & Fisher, 2002; C. C. Miller, 2015). To address the gender gap in educational experience, Carnegie Mellon changed departmental policies so that prior computing experience was no longer a prerequisite for admission to the major (Margolis & Fisher, 2002). University of Washington ran workshops to expose girls and their teachers to computer science before college (C. C. Miller, 2015). In addition, both Harvey Mudd and Carnegie Mellon split their introductory computer science course into two courses—one for students with more prior experience and one for students with less experience. Sending the "geeky know-it-alls" who had previously dominated classroom dynamics to another class helped make interactions between faculty and students in the introductory class more positive for students with less previous computing experience (Hafner, 2012, para. 10). To address the masculine culture, the departments made three changes. First, stereotypes of computer scientists were changed by explicitly discussing those in the field "as more multidimensional than the standard 'boy hacker' icon" at Carnegie Mellon (Margolis & Fisher, 2002, p. 133) and by adding discussions about diversity into the curriculum at Carnegie Mellon and University of Washington (Margolis & Fisher, 2002; C. C. Miller, 2015). Second, all three departments changed stereotypes about the work in computer science by revamping their introductory courses to incorporate real-world applications of computer science to society. Third, female computer science majors at Harvey Mudd and University of Washington got exposure to a supportive peer network and female teaching assistants, through their annual attendance (free-of-charge) at a women in technology conference (Hafner, 2012; C. C. Miller, 2015) and through exposure to a high proportion of female TAs (C. C. Miller, 2015). These departments have been successful because they addressed both the lack of early educational experience and masculine cultures that were preventing women from graduating with computer science degrees. Notably, although an introductory computer science course was mandatory at Harvey Mudd for all students for several years before these changes occurred, this requirement alone was not enough to draw more women into the field. Gender gaps in participation only closed once the department became a place where women were able to learn computer science *in a culture that signaled they belonged*.

Our analysis of STEM fields does not involve single-handedly placing blame for women's underrepresentation on STEM fields themselves, or giving all the credit to fields that have diversified more successfully. Rather, our analysis shows that forces both within STEM (e.g., role models) and outside of STEM (e.g., cultural stereotypes about these fields) come together to influence women and men into some STEM fields over others. Note that work examining other contexts may come up with different factors to explain variability in gender participation. For instance, to explain why postindustrial countries typically have bigger gender gaps in STEM participation than developing countries, researchers have focused on the combination of gender essentialist beliefs—the notion that men and women have different natural abilities—and self-expressive values in career choice (Charles & Bradley, 2009). Similarly, focusing on a different set of fields may yield different conclusions. Looking only at the two largest STEM fields (engineering and biology), would reveal more factors that distinguish these fields than was revealed by including six STEM fields.

How do we reconcile our analysis about masculine cultures with arguments that girls and women have other interests outside of computer science, engineering, and physics and should not be prevented from following their passions (e.g., Gelernter, 1999; Schuman, 2014)? A key message from our analysis is that *women's interests are fundamentally shaped by the culture of these fields*. Just because women are excited to go into other fields does not mean that they would not have been equally excited to go into computer science, engineering, and physics if the cultures signaled to them that they belong there. Like many women (Perez-Felkner et al., 2012), the authors of this article were well prepared for majors in computer science, engineering, and physics upon entering college (e.g., multiple advanced science and math courses, high math SAT scores). However, the culture of these fields, including our inaccurate perceptions about what the people are like, precluded us from putting these fields on the table as a possibility. Although some of these cultural factors were explicitly perceived by us (e.g., people seemed different from us), others were not (e.g., exposure to few relatable role models). The very fact that the process of majoring in a field is framed as a choice in the U.S. can mask the influence of cultural forces. Students who see a poster that describes women who leave work to raise children as "choosing to leave" are less likely to acknowledge that discrimination exists against women than those who see a poster that does not depict women leaving the workplace as a choice (Stephens & Levine, 2011). Preferences adapt to prevailing cultural conditions, oftentimes without people's awareness (Nisbett & Wilson, 1977; Sen, 1992).

Extension of the Model to Explaining Other Disparities

Though our review focuses on explaining variability in gender participation between STEM fields in the U.S., our model may also be applicable to non-STEM fields, STEM subfields, cross-national differences, and men's underrepresentation.

There are many fields, such as social work and nursing, that are not mandatory in early education but which still attract women, likely because their cultures signal an equal or greater sense of belonging to women than men. These fields can be contrasted to other fields such as philosophy and economics that are also not mandatory but which have relatively low percentages of women (31% of undergraduate degrees go to women in both fields; American Philosophical Association, 2013; National Science Foundation, 2014a). Philosophy and economics are similar to computer science, engineering, and physics in that college students perceive aspects of their cultures as being masculine. Both philosophy and economics are associated with stereotypes that are considered more characteristic of men than women (e.g., questioning, self-interested, brilliant; Di Bella, Miles, & Saul, 2016; Hellmich, 2012; Lanteri & Rizzello, 2007; Leslie et al., 2015; Thompson, Adleberg, Sims, & Nahmias, 2015). Introductory philosophy

classes are also perceived as biased against women and less relevant to women's than men's lives (Thompson et al., 2015).[9] When early educational experience is low, students' perceptions of the culture of the field may determine who enters and who does not belong.

Our model can also be extended to shed light on within-field gender gaps in participation. In computer science, women are more highly represented in human-computer interaction than robotics (Bizot, 2012). In engineering, women are more likely to be represented in chemical, biomedical, and architectural engineering than in electrical, mechanical, and nuclear engineering (Yoder, 2014). In philosophy, feminist philosophy, applied ethics, and social philosophy/social theory have the highest percentage of women while metaphysics, epistemology, and philosophy of mind have the highest percentage of men (Haslanger, 2010). Even within surgical subspecialties, women constitute 36% of general surgery residents and fellows but only 13% of orthopaedic surgery residents and fellows (Association of American Medical Colleges, 2012). To date, very little research has offered an explanation for why women gravitate to some subfields while men gravitate to others. Our model suggests that insufficient early experience, masculine cultures, and gender gaps in self-efficacy may play a significant role in shaping preferences for one subfield over another. In support of this, the American Academy of Orthopaedic Surgeons suggests that little exposure to musculoskeletal training in medical school, a perceived "old-boys network," stereotypes that women are a "bad investment" (Porucznik, 2008), a perceived "jock/frat culture," and few role models (O'Connor, 2012) come together to preclude women from choosing orthopedic surgery. Our model may explain gender disparities within fields as well as between them.

Our analysis may also be relevant beyond the U.S. First, women's underrepresentation in computer science, engineering, and physics compared with biology and chemistry appears to be present across many countries (Baram-Tsabari & Yarden, 2008; Dresselhaus, Franz, & Clark, 1994; Galpin, 2002; Sikora & Pokropek, 2012). Consistent with our model, a review on women's participation in STEM points to the "ubiquitous nature of gendered stereotypes expressing an association between science and 'essential' male characteristics" to explain why women are granted approximately 20% of undergraduate degrees in physics and 10% of undergraduate degrees in computing in the U.K. (Bennett, 2011, p. 152). Second, our model might shed light on cross-national variability. In Malaysia, computer science is not and has never been male-dominated. Computer science in Malaysia is not associated with masculine characteristics and is instead seen as highly appropriate for women, in part due to the presence of female role models and perceptions of the work as "indoor work" (Mellström, 2009). Consistent with our model, a lack of a perceived masculine culture in Malaysia may be drawing women into computer science.

Though we have mainly focused on explaining women's choices and interests, underrepresentation involves men's choices as much as women's choices. Men continue to face strong norms to be masculine (Cheryan, Cameron, et al., 2015; Vandello, Bosson, Cohen, Burnaford, & Weaver, 2008), and stereotypes of men have remained relatively fixed over time while stereotypes of women have changed to make stereotypically masculine traits more acceptable for women (Diekman & Eagly, 2000; Prentice & Carranza, 2002). Even if women were immune to the masculine

culture of STEM, these cultures may still produce gender disparities if they disproportionally encourage men into the field. The field of computer science provides a good historical example. The proportion of women receiving computer science degrees has been declining nearly every year since the mid-1980s. This decrease has been due more to an influx of men than a decrease of women (between 1985 and 2013, the number of men earning bachelor's degrees in computer science increased by 17,687 whereas the number of women dropped by 5,222; Iskander et al., 2013; National Science Foundation, 2014a). What happened in the 1980s? According to cultural historians, the masculine "nerdy" image of computer scientists crystallized during this decade with the rise of the personal computer and widely circulated associated images of the successful male computer genius (e.g., Steve Jobs, Bill Gates; Misa, 2010). This image may have signaled to generations of boys that they belong in computer science and would be successful there just as much as (or even more than) it signaled to girls the opposite (Cheryan et al., 2009). Considering how cultural forces act on men's choices and interests is important to understanding gender disparities in computer science, engineering, and physics.

Our model can also help explain gender disparities in fields and careers in which men are underrepresented (e.g., nursing, domestic roles). First, stereotypes of people in these fields are incompatible with the male gender role that prescribes that men are breadwinners and agentic (Wood & Eagly, 2012). Second, men are stereotyped as lacking childcare and empathetic skills (Clark, Thiem, Barden, Stuart, & Evans, 2015). Third, men see few relatable role models in female-dominated domains (Croft, Schmader, & Block, 2015). Cultures of these fields may thus cause many men to feel like they do not belong in them. Men are just as likely as women to be deterred from fields if they do not feel a sense of belonging in them (Cheryan et al., 2009; Good et al., 2012). Boys are also likely to get little early experience with these fields. Getting more men to be interested in female-dominated occupations and spheres (see Croft et al., 2015, for an argument about why this is important) would thus entail changing male gender norms, changing cultures to signal to men that they belong in these professions, and providing early experiences to boys to prepare them for such professions. Changing cultures to signal a sense of belonging is not only relevant for women.

Places for Future Work

Most papers have focused on only one STEM field or collapsed across all of STEM. Very few papers have compared STEM fields to one another (for exceptions see Cohoon, 2002; Deemer et al., 2014; Leslie et al., 2015; Milkman et al., 2015; Ost, 2010). Our review aggregated findings from different fields and compared them to one another to determine which factors predicted current patterns of underrepresentation. An important next step is to conduct studies investigating several fields and factors together to

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[9] We could find no empirical work on high school students' perceptions of philosophers or economists or the prevalence of negative stereotypes about women's abilities in these fields. More work is needed to uncover whether students enter college with stereotypes that cultures are masculine or acquire that perception in college. About 40% of students in introductory philosophy and economics courses in college are women (Paxton, Figdor, & Tiberius, 2012; Rask & Tiefenthaler, 2004; see Schouten, 2015, for a discussion about the differences between philosophy and STEM).

identify relative weights of these factors in accounting for current disparities and how they interact with one another to produce gender disparities. Moreover, future work could examine whether this model explains gender differences in participation rates between subfields (e.g., human computer interaction vs. robotics in computer science) and between non-STEM fields (e.g., economics vs. sociology).

Future work should also investigate how these and other factors operate in other educational contexts and with students from diverse backgrounds. Much of the literature to date has been focused on understanding how to increase the number of women who enter and persist in STEM, but we believe a more appropriate question is how to democratize STEM fields so that everyone has access to high quality learning experiences (Ryoo, Margolis, Lee, Sandoval, & Goode, 2013). Such an approach necessitates paying attention to other identities (e.g., race, class, sexual orientation, disability, age) and moving outside the 4-year university context to investigate students in community colleges and for-profit universities. Students with lower socioeconomic backgrounds may exhibit a weaker link between their interests and their choice of majors than students from higher socioeconomic backgrounds (Tucker-Drob, Cheung, & Briley, 2014). Students from lower SES backgrounds may be more motivated than students from higher SES backgrounds to select fields that will lead to financial stability. Yet at the same time, these students may have less access to advanced STEM courses, making it more difficult to enter and persist in STEM (Chen, 2009; Ercikan, McCreith, & Lapointe, 2005). More empirical work is needed on how social class and other identities intersect with gender to influence participation.

There are numerous interventions currently underway to motivate more girls and women to enter and remain in STEM fields. More of these efforts should be conducted in a scientific manner and made widely known so that their successes can be evaluated, documented, and disseminated.

Conclusion

In 2014, Maryam Mirzakhani became the first woman to win the prestigious Fields Medal, the highest honor that is given to a mathematician. As a child, Dr. Mirzakhani's career goal was to become a writer. It took a combination of factors to encourage her pursuit of mathematics. She took several math courses and started to enjoy them. Her older brother exposed her to math problems he was learning in school. She became good friends with a girl in middle school who enjoyed math (and who also eventually became a math professor). Her high school principal changed the system to allow girls to participate in an extracurricular advanced math program. According to Dr. Mirzakhani, "the more I spent time on mathematics, the more excited I became" (Clay Mathematics Institute, 2008).

How do the majority of girls in the U.S. experience computer science, engineering, and physics today? They are exposed to them most prominently in the media, where most people in these fields are depicted as male, socially awkward, and intensely focused on machines. The lucky ones may get some exposure through summer or afterschool programs, but most may never get high-quality and sustained experience or meet a role model or mentor in one of these fields with whom they relate. Some may take a computer science, engineering, or physics course in high school or college and find that they are less prepared for the course than their male peers. Throughout it all, they face stereotypes that girls are not as good as boys at these fields. Imagine the possibilities if girls could learn computer science, engineering, and physics the way they do other fields, and within cultural environments in which they feel a sense of belonging equal to that of their male peers.

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