

# The STEM paradox: Factors affecting diversity in STEM fields

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**Abstract.** 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 (NSF). Why are women represented in some STEM fields more than others? The STEM Paradox or Gender Equality Paradox show that countries with greater gender equality have a lower percentage of female STEM graduates. This phenomenon as well as other factors explaining gender disparities in STEM participation and some possible solutions are discussed.

## 1. Introduction

The underrepresentation of women in Science, Technology, Engineering, and Mathematics (STEM) fields is a worldwide concern that has economic, social, and political consequences [1, 2, 3, 4, 5]. The gender gap is particularly significant among computer science, engineering, and physics, fields that focus on inorganic phenomena. According to the National Science Foundation [6], women obtain 57% of all U.S. undergraduate degrees in biology, chemistry, and mathematics since the late 1990s, yet they earn less than 20% of computer science, engineering, and physics undergraduate degrees. Women earn just one-fourth of the doctorates in mathematics and statistics. Fields are missing out on potential contributions of talented women and on benefits of having gender diversity, including greater creativity, innovation, and collective intelligence. Diversity powers innovation. Additionally, women may be missing out on lucrative careers that are high in status, and some countries may lose their competitive advantages in certain fields. Despite significant efforts to better understand why this underrepresentation remains rather stable over time, no clear answers have emerged. The failure of current approaches calls for a new perspective on the issue.

Several researchers have proposed that women's and men's preferences for certain career fields may be constrained and expanded by cultural factors [4, 5]. Recently, Stoet and Geary analyzed data on adolescent achievement in science, mathematics, and reading from 472,242 students across 67 countries. They found that whereas boys' and girls' achievements in STEM subjects were broadly the same in all countries, science was more likely to be the boys' best subject (intraindividual strength). Even when girls' abilities in science equaled or exceeded that of boys, they were more likely outperforming boys in overall reading comprehension, which relates to higher ability in non-STEM subjects. Throughout the world, boys' intraindividual academic strengths tended to be in science or mathematics, whereas girls' intraindividual strengths were in reading. These gender differences in intraindividual strengths, as well as interest (girls had lower interest in science subjects) may explain why the gender differences in STEM fields has been stable over decades, and why current approaches to address them have failed.

## 2. STEM paradox

Stoet and Geary's research showed that countries with high levels of gender equality [8] have some of the largest gender gaps in STEM fields in secondary and higher education. The researchers called this gender gap the *educational-gender-equality paradox* (or STEM paradox). Finland, which according to the World Economic Forum ranks toward the top of the gender equality scale, and whose girls outperform boys in science literacy, has one of the largest gender gaps in college degrees in STEM fields. Women in Finland only account for 10% of the physics professors at the University of Helsinki, despite the fact that over 20% of the Ph.D. degrees in physics have been completed by women since 1996 [9]. Similar results can be found in Norway and Sweden that also lead in gender-equality. In Sweden, for example, only 34% of engineers are female. That number is even lower in the U.S. with 19% female engineers [6]. Stoet and Geary found that the higher the gender equality in a country, the fewer women in STEM fields. Conversely, in many Muslim-majority countries there are more female than male engineers. For example, in Iran, 70% of university graduates in STEM are women. In the United Arab Emirates, Oman, and Saudi Arabia, 60% of STEM graduates are women. Why would we expect such significant cultural differences?

In more socially progressive countries, women are actively encouraged to participate in STEM; yet, they lose more girls because of personal academic strengths. One explanation may be that in more wealthy countries, personal preferences seem to be more strongly expressed. This may lead to gender differences in intraindividual academic strengths and interests becoming larger and having a stronger influence on college and career choices in more conservative, less wealthy countries, creating the gender-equality paradox [5]. In addition, welfare support in wealthy countries makes choices of highly paid STEM jobs less attractive than in less affluent countries where a lucrative and more stable STEM job helps elevate a woman's social and economic status.

### 2.1 Possible Factors in the underrepresentation of women in STEM fields

Much of the current research has focused on which factors across development (from prenatal hormones to tenure rates) contribute to women's underrepresentation among STEM faculty [2, 3, 9]. Ceci concluded that math-capable women disproportionately chose non-mathematics fields for their careers. These preferences appear during adolescence. Others have investigated the robust gender differences in visuospatial skills [10, 11, 12, 13, 14] as a possible factor why women may not chose STEM fields. Spatial ability, which is the capability to represent and transform symbolic or non-linguistic information through space, is critical in a number of different academic and professional STEM fields [15]. On average, males surpass females on mental rotation tasks and other visuospatial skills tests. These gender differences are related to differential childhood experiences. For instance, studies have shown that experiences with map reading, certain sports, spatial toys and 3D videogames affect mental rotation skills [16, 17, 18, 19, 20]. Cherney and Voyer developed the childhood activities questionnaire that measures the type and relative frequency of activities that participants enjoyed as children. It has shown to predict spatial abilities in adulthood [21] and suggests that children who spend more time during their childhood doing spatial activities (e.g., sports that use eye-hand coordination, playing with masculine and building toys and video games, etc.) develop better visuospatial skills. Video game experience and training have also shown to decrease the gender disparity on mental rotation tests [10, 18, 22]. For example, Cherney showed that a one hour training on a 3D video game can reduce the gender difference on a mental rotation task [10].

2.1.1. *Preferences for some STEM fields and a few possible causes.* Current studies do not generally explore why gender differences in preferences for some STEM fields are significantly different from gender differences in other fields. Cheryan *et al.* examined the cultures of STEM fields and why some fields have achieved greater gender parity whereas others continue to have significant gender gaps in participation [4]. Preferences for certain careers do not develop in a vacuum and are constrained and expanded by cultural factors. The culture of STEM is often described as masculine and a hostile place for women [23]. However, STEM fields are not uniformly the same and different cultures within certain

fields exist when it comes to gender [24]. For example, STEM fields differ in the extent to which they are associated with masculine stereotypes [24]. In addition, even if the culture of a STEM field is not overtly hostile to women, the latter will be less likely to enter, persist, and be successful in a field when there is a mismatch between the way they wish to be seen and expected to behave, and the norms of that culture [4]. Examining the six largest natural science and engineering fields at the college level [25], Cheryan *et al.* found the biological sciences, chemistry, and mathematics and statistics are relatively gender-balanced, whereas computer science, engineering, and physics are highly male-dominated. They reviewed over 8000 articles in various disciplines and found several factors that may exacerbate the different sub-cultures in STEM fields. First, the type of masculinity associated with computer science, engineering, and physics differ from the traditional definition of masculinity. In those sub-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 [26]. Second, people in STEM are considered having traits and characteristics that are associated with males, and a belief that they have masculine traits and interests. Computer scientists, engineers, and physicists are seen as stereotypically male [27]. Third, the stereotypes about the work in the fields differ. There are three stereotypes that have been theorized to explain gender differences in STEM: a) whether the content of the work is people-oriented [28], b) whether the work fulfils goals of achieving power and status [29], and c) the belief that achieving success in the field requires brilliance [24]. Fourth, higher earning potential seems to disproportionately attract males to those fields, at least in wealthy countries. All of these factors were found to increase the gender gap in the sub-fields of computer science, physics, and engineering [4].

*2.1.2. Role Models* Other factors that were identified in Cheryan *et al.*'s study are the lack of female role models in the various STEM fields [4]. Because of women's existing underrepresentation in engineering, physics and computer science, there are fewer potential female role models in these fields compared to biology, chemistry, or mathematics. Some interventions using female role models or mentors to increase girls' interest and participation have met some success [30], but other studies have shown no increase in interest to pursue a STEM career in young females in single-sex schools where the vast majority of their teachers were female [3].

*2.1.3. Course Offerings* Course offerings in schools have also been proposed as factors influencing women's career choices. 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. Even when high schools offer computer science, engineering or physics classes, many students in the U.S. will not take these classes because they have the freedom to opt out of them. Girls are much less likely than boys to take courses in computer programming, engineering, and physics at the high-school and college levels [31]. Boys are thus more likely to enter higher education with more courses and experience in these sub-fields.

*2.1.4. Self-efficacy* In addition, gender gaps in self-efficacy are likely contributing to the underrepresentation of women in STEM fields, particularly in computer science, engineering, and physics. Self-efficacy is the belief that one has the capacity to be successful at a particular task [32]. Among high school and undergraduate students women report lower self-efficacy and lower self-view (perceptions of one's abilities and skills in STEM) than men in computer science, physics, and engineering [33, 4]. These differences may be partially explained by the lower math self-efficacy in girls [34]. These gender differences may stem from the multiple influences of parents, peers, and the schools on children's development [15]. For example, parents tend to assign higher math ability to their sons. Although one cannot infer the direction of causality with correlational data, numerous studies have confirmed the finding that parents' expectations for their children's academic abilities and success are correlated with the children's self-concept of their own ability and subsequent performance [15]. Taken together, these factors and many others contribute to the lower representation in certain STEM fields.

These studies show that there are important cultural differences among the various STEM fields that should be further examined.

*2.1.5. Stereotypes and stereotype threat* Many studies have also pointed to the role of stereotypes, and in particular stereotype threat as factors that turn away women from quantitative careers. Careers in science and math are typically considered masculine [15]. In stereotype studies, the researchers generally make a well-known stereotype salient before the participants take a high-stakes test. This slight manipulation is enough to lead to different test scores between those who have been exposed to the stereotype threat and those who have not [35]. The context in which these tests are administered has been shown to affect girls more than boys. Many studies have shown that men outperform women in math, more so when the threat is made explicit. Stereotype threat findings do not imply that all gender differences in math performance can be eradicated by such manipulations. However, they do suggest that stereotype threat can undermine some women, perhaps especially mathematically talented ones. Cherney and Campbell conducted a study on 548 U.S. boys and girls from single-sex and coeducational high schools. Half of the participants were in a stereotype threat condition where a well-known stereotype (women typically score less well on this math test) was made salient and half of the participants were not exposed to the stereotype (there are no difference between men and women on this math test). Students wanting to pursue a STEM field tended to have higher math scores than those wanting to pursue non-STEM careers. Interestingly, girls in single-sex schools who were in the stereotype threat condition outperformed those who were not in the stereotype threat condition. This may be explained by a phenomenon called the stereotype reactance effect. When a negative stereotype is explicitly activated, it might be perceived by test takers as a limit to their freedom and ability to perform, thereby invoking behaviors that are inconsistent with the stereotype. This reactance may be more prevalent under same-sex group testing [3]. However, despite the higher math performance, higher numbers of female role models, higher self-esteem and higher intrinsic motivation, the girls in single-sex schools were not more likely than those in the coeducational schools to want to pursue a career in the physical sciences.

## *2.2 A few possible solutions to reduce gender gap*

How do we increase diversity in STEM fields? Stoet and Geary's results indicate that achieving parity in STEM fields will take a lot of planning and more than raising overall gender equality. The often overlooked intraindividual differences in academic competencies and accompanying influence on one's expectancies of the value of pursuing certain careers over others will need to be incorporated into approaches for encouraging more women to enter STEM fields. Interventions might be best done with high-achieving girls who enjoy science and math. Because children and adolescents are strongly influenced by peers, creating peer groups who enjoy doing science and math might increase their academic motivation. Overall, the STEM paradox suggests that individual students make decisions and attitudes that are likely influenced by broader socioeconomic considerations.

Roots of gender disparities in science achievement take hold in early childhood. The types of toys that children play with has long-term consequences [16]. Children choose different lifestyle habits that last into adulthood. During leisure time, boys spend more time playing outdoors in active and dynamic play, whereas girls spend more time playing indoors and in more static types of play [17]. Because different activities promote differential cognitive, social, and motor skills, it is important to expose girls to activities that develop spatial skills early because these skills have been shown to be important for many STEM fields. Providing girls more opportunities to play with stereotypically masculine and spatial toys, as well as play sports that involve eye-hand coordination would increase their spatial abilities and may increase their preference for these activities, and ultimately increase their self-efficacy in their abilities [16, 17]. Playing 3D video games more frequently would likely increase girls' spatial skills as well [10].

A recent study [36] also showed that describing science in terms of actions ("Let's do science") instead of identities ("Let's be scientists") increased girls' persistence in new science games that use the

scientific method. This subtle change in linguistic cues could be used to engage more girls in science during the early, formative years. Overall, it is important to remember that verbal cues contribute greatly to the development of stereotypes, which in turn are internalized, and may have negative consequences on children's achievement and motivations. More engagement may provide girls with higher self-efficacy, which in turn might increase their interest in STEM fields. They might then be more likely to see science as a career option. Strategies aimed at improving female representation in physics should emphasize physics interest rather than performance or competence. As mentioned earlier, adolescent girls often prefer careers focusing on people as opposed to things. Market to girls that careers in computer science, engineering, and physics save people's lives or at a minimum "help" people. It is also important to make coding more fun and attractive for girls. Currently, more companies are developing robots and computer apps that help children code at a young age. More and more school districts are adopting curricula that include digital literacy and computer science. These early interventions may show success in the years to come, as perhaps coding will be perceived as a subject as important as reading, writing, and math.

Schools can develop a strong culture of inclusion and experimentation. Teachers are more likely to encourage boys to ask questions and to explain concepts during science classes [15]. Similarly, parents explain the science process in more depth to their sons than their daughters. Even small changes made in the classroom and at home can have long-lasting effects on a child's self-concept, self-esteem, and self-efficacy. Teachers and counsellors should be encouraging girls and boys equally to pursue careers in the sciences.

Organizations and companies should recruit a more diverse work force. Hiring managers should conduct blind reviews of resumes. Studies have shown that merely changing a person's name on a resume from male to female or from a white applicant to a black applicant decreases the likelihood of the presumed applicant's hiring [37]. This type of unconscious bias in the workplace is rather common. The social stereotypes about certain groups of people that individuals form outside of conscious awareness happens automatically. To avoid bias, it is important to be aware of them, to question them, and to create inclusive policies. Managers should determine and understand the need for diversity and inclusion in their organization and dedicate resources to those policies. Inclusion may mean communicating to all parties that important meetings should take place during hours when parents can be present and attend the meetings. Perhaps the organization can subsidize child care to attract and retain all talented people. Pay equity is fundamental and should be instituted at every level of the organization. Leaders must establish a culture of accountability and assessment and support a climate that values diversity, equity, and inclusion so all members of the community thrive.

### **3. Conclusions**

The STEM paradox highlights somewhat new factors that influence the underrepresentation of women in STEM fields, namely gender equality. Using the most current and largest database on adolescent achievement, Stoet and Geary found that girls and boys performed similarly on generic literacy tests in most countries, even though women obtained fewer college degrees in STEM subjects than men in all the assessed nations [5]. The loss of female STEM capacity seemed to happen between secondary and tertiary education. The paradox lies in the fact that countries with higher levels of gender equality had relatively fewer women among STEM graduates than did less gender equal countries. These gender differences are expected on the basis of expectancy-value theory [38] which predicts that individuals will make career decisions based in part on their personal strength, which is a common advice given to students by counsellors and parents.

These findings demonstrate that achieving the goal of parity in STEM fields will take more than improving girls' science education and raising overall gender equality. Intraindividual academic competencies and one's expectancies of the value of pursuing a certain career over another (similar to the underrepresentation of men in nursing and early education) will need to be incorporated into approaches for encouraging more women to enter the STEM pipeline (and more men to enter the nursing pipeline).

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