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With Big Data Comes Big Responsibilities for Science Equity Research

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Our ability to collect and access large quantities of data over the last decade has been revolutionary for many social sciences. Suddenly, it is possible to measure human behavior, performance, and activity on an unprecedented scale, opening the door to fundamental advances in discovery and understanding. Yet such access to data has limitations that, if not sufficiently addressed and explored, can result in significant oversights. Here we discuss recent research that used data from a large global sample of high school students to demonstrate, paradoxically, that in nations with higher gender equality, fewer women pursued science, technology, engineering, and mathematics (STEM) degrees than would be expected based on aptitude in those subjects. The *reasons* for observed patterns is central to current debates, with frequent disagreement about the nature and magnitude of problems posed by the lack of female representation in STEM and the best ways to deal with them. In our international efforts to use big data in education research, it is necessary to critically consider its limitations and biases.

Vores evne til at indsamle og bearbejde store mængder data, er i løbet af det sidste årti revolutioneret. Pludselig er det muligt at måle menneskers adfærd, evner og aktiviteter i et hidtil uset omfang. Det åbner for grundlæggende landvindinger i vores forståelser. Dog har sådanne data også begrænsninger, som hvis de ikke tilstrækkeligt adresseres og udforskes, kan føre til væsentlige vildfarelser. Vi diskuterer i denne artikel nyere forskning, der har anvendt data fra en stor global sample af gymnasieelever for at demonstrere, paradoksalt nok, at i lande med højere ligestilling mellem kønnene, søger færre kvinder mod naturvidenskab, teknologi, ingeniørfagene og matematik (STEM), end man kunne forvente baseret på elevernes forudsætningerne til disse fag. Årsagerne til disse mønstre er et centralt input til aktuelle debatter om arten og størrelsen af problemerne som følge af manglen på kvinder i STEM, og de bedste måder at håndtere dem på. I de internationale bestræbelser på at bruge Big Data i uddannelsesforskning, er det nødvendigt kritisk at overveje såvel begrænsninger som bias.

INTRODUCTION

In 2015, a sample of 472,242 high school students in 72 nations and regions across the world sat down and took a two-hour assessment that gauged their science, mathematics, and reading comprehension skills. Using these data, researchers demonstrated a surprising counter-intuitive pattern: in *more* gender-equal countries, such as Denmark and Sweden, 15-year-old girls with strengths in science disciplines were more likely leave an academic STEM track (science, technology, engineering, and math) in favor of one that aligned with their reading comprehension skills than girls in *less* gender-equal countries, such as Yemen and Syria (1). Gender equality in this context was measured by the annual Global Gender Gap Report published by the World Economic Forum (2). The report assigns an index to each country that reflects relative gender parity on 14 key indicators such as educational attainment, life expectancy, wage equality, and representation in government. Many reporters pointed to these results while throwing their hands in the air and shrugging their shoulders, concluding that there is just something inherently different about men and women (but they are roughly the same within those two groups), and that greater freedom in more gender-equal countries leads to greater sex-based career divergences because women preferentially choose paths that align more with their interests, which are not in STEM (e.g., https://www.bizjournals.com/bizwomen/news/latest-news/2018/03/a-surprising-reason-girls-steer-away-from-stem.html?page=all).

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This is one interpretation of the analysis presented in the paper—that women who perform well in STEM topics are *lured away* from STEM in pursuit of humanities degrees because science simply does not interest them. This rosy interpretation of the results overlooks another factor that influences gender representation in STEM—that women can be pushed—*not pulled*—out of STEM fields, and that more egalitarian societies provide women with better opportunities and financial security to support themselves in a non-STEM field (e.g., a career in the humanities, which aligns with strong reading comprehension skills) if they decide to leave a more lucrative STEM degree. That is, the barriers for women in gender-equal countries may still exist, but in such places women also have relatively good options outside of STEM (2, 3). The amount of energy one should invest in overcoming systemic barriers is low when the reward for doing so is low. In less gender-equal countries, women have fewer opportunities for professional success outside of STEM. In this scenario, the amount of energy one should invest in overcoming systemic barriers is high because the reward for doing so is high. The study's authors also point out that quality-of-life pressures in countries with less gender equality keep women *in* STEM subjects (1). In other words, women in those countries may remain in STEM in spite of existing barriers because a high-paying STEM career may seem to be an investment in a more financially secure future.

The availability of large datasets has caused shifts in our approach to science. With access to big data, it is easier to develop models of behavior and describe a system without explaining or making *a priori* predictions of the underlying phenomena. So why do women in countries with greater gender equality who *could* enter STEM fields make other choices? Cultural and social forces still function as barriers to women as they struggle to reach the very top of STEM fields, and the reasons women opt out of STEM are actually pretty well documented globally (4, 5). So before we assume that, given the choice, women will generally *not* pursue STEM fields because of a lack of "innate" interest, we should consider the existing research.

Why leave science?

Ask a child what they want to be when they grow up, and odds are that if they answer "a scientist," they received encouragement and support early in their education from teachers and family. Stereotypes of scientists develop as early as six years old (6, 7) and can shape adolescents' perceptions of who can be a scientist. The stereotype generally aligns with the demographic group that historically had greatest access to the discipline: white, middle-class men. A range of Scandinavian studies shows how the content and study culture within science tend to favor certain experiences (8), interests (9, 10), and practices (11) that are gendered. For example, one study documented that primary school girls' motivations to pursue science included the cross-disciplinary aspects of science and the ability to use science as a means to create solutions to societal challenges. These interests were not included in the course curriculum to the same extent as the boys' stated motivations (12). In fact, interviews with students in Danish upper-secondary school revealed that students perceive science as stable and rigid and found no personal connection between the curriculum and the world or their daily lives (13). Education is free in much of Scandinavia, with a history of economic security and the expectation that academic study should not only produce students who are competitive in terms of entering the workforce, but also be a platform for personal fulfillment. This means that students are not required to make a financial investment in their chosen topic of study, unlike those in less gender-equal countries. These studies highlight the fact that science curricula are often products of historical traditions rather than subject to change based on the needs and interests of an increasingly diverse talent pool.

Though teachers often have the best of intentions, research demonstrates how classroom practices vary based on student gender. Francis (2002) provides a number of examples of British secondary school teachers' differential treatment of boys and girls that rewards boys for being outspoken and bold and girls for being passive and compliant (14). Not surprisingly, "passive" and "compliant" are not traits associated with science and discovery. Within the context of the science classroom, this puts girls and women in a double bind: the pressure to conform to a gender stereotype directly conflicts with professional expectations (15). Unconscious gender bias from parents and teachers has been documented among children in kindergarten, adolescence, and early adulthood (16–18); girls are simply perceived as less talented than their male classmates and are less likely to be recognized as (and recognize themselves as) "science" persons (19, 20).

At the undergraduate and graduate level, women must tolerate overt barriers such as discrimination (21, https://www.theguardian.com/world/2018/aug/08/tokyo-medical-school-admits-changing-results-to-exclude-women), sexual harassment, and denial of gender bias in science despite scientific evidence (22). Undergraduate women also face more subtle hurdles such as a lack of role models in the form of instructors or disciplinary visionaries (23, 24), grades that rely primarily on high-stakes exams (25, 26), microaggressions from students and instructors (27), and unconscious bias from peers (28).

CONCLUSIONS

It is not easy to pin down the specific features that influence students' interest in STEM (or their decision to leave it), which are highly heterogeneous and can vary based on many factors, complicating attempts to effectively promote students or mitigate their attrition at scale. Nevertheless, the essential features of any scientific pursuit include documenting patterns and processes, developing and testing hypotheses, and refining existing ideas and descriptions observed based on new data and insights. This paper has documented an interesting pattern worthy of further investigation. However, there is nothing "inherent" about complex gender differences that might explain why women choose to pursue science, or to leave the discipline.

Instead of using these data to define what men and women "are like" in absolute terms, a more useful response to this paper would be to recognize the importance of improving systemic failures of organizations in attracting young people to science within gender-equal countries. For example, work in the United States shows large introductory science courses impose gendered grade penalties that negatively impact women (29, 30), perhaps due to high-stakes exams that largely determine course grades (25) or large class sizes (31). Effective approaches that address problems inherent to introductory science courses include reducing the proportion of students' final grades that is based on exams (26), reducing class sizes (32), or facilitating peer-led instruction (33, 34). Others point to the importance of engaging children in science at early stages of their education (35, 36). "Discrimination" includes the *absence* of support structures (i.e., infrastructure) that are inherently supportive of girls and women. That absence increases the cost of participation in certain fields, whether it is STEM or some other endeavor. Future research should address the following: What support structures are absent? What support structures are present with respect to other fields? Women are not alone in experiencing these forms of discrimination—research documents that students who are underrepresented ethnic minorities (37, 38), are from low socioeconomic backgrounds (39), or fall along the spectrum of lesbian, gay, bisexual, transgender, queer, intersex, and asexual (LGBTQIA) identities (40, 41) also face similar challenges throughout the STEM pathway.

The article shows that girls reported lower enjoyment of science. To the extent that women's and girls' choices are freely made in a fair environment, then there is no problem. However, it is unquestionably a desirable outcome for all to be able to compete without the disadvantage of institutional discrimination. If students are opting out of a discipline due to discrimination, misinformation, or stereotypes, then we must continue to advocate for strategies to combat observed shortages. Future work should harness large datasets to inform how we understand and address fundamental patterns responsible for disparities and our international efforts to resolve them.

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