With big data comes big responsibilities for science equity research

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English abstract

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, at an unprecedented scope, which opens 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, less 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.

Danish abstract

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, ingeniør-fagene 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 2-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 preferably choose paths that align more with their interests, which is not in STEM (e.g., https://www.bizjournals.com/bizwomen/news/latest-news/2018/03/a-surprising-reason-girls-steer-away-from-stem.html).

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 a humanities degree 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 align 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 less 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 well-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 also 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 by teachers and their 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 who historically had greatest

104 access to the discipline: white, middle-class men. A range of Scandinavian studies show how the content
105 and study culture within science tend to favor certain experiences (8), interests (9, 10), and practices
106 (11) that are gendered. For example, one study documented that primary school girls' motivations to
107 pursue science included the cross-disciplinary aspects of science and the ability to use science as a
108 means to create solutions to societal challenges. These interests were not included in the course
109 curriculum to the same extent as the boys' stated motivations (12). In fact, interviews with students in
110 Danish upper-secondary school revealed that students perceive science as stable, rigid, and found no
111 personal connection between the curriculum and the world or their daily lives (13). Education is free in
112 much of Scandinavia, with a history of economic security and the expectation that academic study
113 should not only produce students who are competitive to enter the workforce, but also be a platform
114 for personal fulfillment. This also means that students are not required to make a financial investment in
115 their chosen topic of study, unlike those in less gender-equal countries. These studies highlight the fact
116 that science curricula are often products of historical traditions rather than subject to change based on
117 the needs and interests of an increasingly diverse talent pool.
118
119 Though teachers often have the best of intentions, research demonstrates how classroom practices vary
120 based on student gender. Francis (2002) provides a number of examples of British secondary school
121 teachers' differential treatment of boys and girls that rewards boys for being outspoken and bold and
122 girls to be passive and compliant. Not surprisingly, 'passive and compliant' are not traits associated with
123 science and discovery. Within the context of the science classroom, this puts girls and women in a
124 double bind: the pressure to conform to a gender stereotype directly conflicts with professional
125 expectations (15). Unconscious gender bias from parents and teachers have been documented among
126 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) a “science” person (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

Pinning down the specific features that influence students’ interest in STEM (or their decision to leave it) 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 show large introductory science courses impose gendered grade penalties that

151 negatively impact women (29, 30), perhaps due to high stakes exams that largely determine course
152 grades (25) or large class sizes (31). Effective approaches that address problems inherent to introductory
153 science courses include reducing the proportion that exams account for in students' final grades (26),
154 reducing class sizes (32), or facilitating peer-led instruction (33, 34). Others point to the importance of
155 engaging children in science at early stages of their education (35, 36). "Discrimination" includes
156 the ***absence*** of support structures (think of it as "infrastructure") that are inherently supportive of girls
157 and women. That absence increases the cost of participation in certain fields, whether it is STEM or
158 some other endeavor. Future research should address -- what support structures are absent? What
159 support structures are present with respect to other fields? Women are not alone in experiencing these
160 forms of discrimination – research documents students who are underrepresented ethnic minorities (37,
161 38), from low socioeconomic backgrounds (39), those who sit along the spectrum of lesbian, gay,
162 bisexual, transgender, queer, intersex, and asexual (LGBTQIA) identities (40, 41) also face similar
163 challenges throughout the STEM pathway.
164
165 To the extent that women's and girls' choices are freely made in a fair environment, then we have no
166 problem. However, it is unquestionably a desirable outcome for all to be able to compete without the
167 disadvantage of institutional discrimination. If students are opting out of a discipline due to
168 discrimination, misinformation, or stereotypes, then we must continue to advocate for strategies to
169 combat observed shortages. Future work should harness large datasets to inform how we understand
170 and address fundamental patterns responsible for disparities and our international efforts to resolve
171 them.
172
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References

1. Stoet G, Geary DC. 2018. The gender-equality paradox in science, technology, engineering, and mathematics education. Psychol Sci 0956797617741719.
2. The Global Gender Gap Report. 2016. The Global Gender Gap Report. World Econ Forum, Geneva, Switz.
3. Sainsbury D. 1999. Gender and welfare state regimes. Oxford University Press.
4. Clark Blickenstaff J. 2005. Women and science careers: leaky pipeline or gender filter? Gend Educ 17:369–386.
5. Hill C, Corbett C, St Rose A. 2010. Why so few? Women in science, technology, engineering, and mathematics. ERIC.
6. Chambers DW. 1983. Stereotypic images of the scientist: The Draw-a-Scientist Test. Sci Educ 67:255–265.
7. Bian L, Leslie S-J, Cimpian A. 2017. Gender stereotypes about intellectual ability emerge early and influence children's interests. Science (80-) 355:389–391.
8. Sinnes AT, Løken M. 2014. Gendered education in a gendered world: looking beyond cosmetic solutions to the gender gap in science. Cult Stud Sci Educ 9:343–364.
9. Schreiner C. 2006. Exploring a ROSE garden: Norwegian youth's orientations towards science: seen as signs of late modern identities.
10. Schreiner C, Sjøberg S. 2007. 16. SCIENCE EDUCATION AND YOUTH'S IDENTITY CONSTRUCTION-TWO INCOMPATIBLE PROJECTS? re-emergence values Sci Educ 231.
11. Danielsson AT. 2009. Doing Physics--doing Gender: An Exploration of Physics Students' Identity Constitution in the Context of Laboratory Work. Anna Teresia Danielsson.
12. Sjøberg S, Schreiner C. 2012. Results and perspectives from the rose project, p. 203–236. *In* Science Education Research and Practice in Europe. Springer.

13. Holmegaard HT, Madsen LM, Ulriksen L. 2014. To choose or not to choose science: Constructions of desirable identities among young people considering a STEM higher education programme. Int J Sci Educ 36:186–215.
14. Francis B. 2002. Boys, girls and achievement: Addressing the classroom issues. Routledge.
15. Ong M, Wright C, Espinosa L, Orfield G. 2011. Inside the double bind: A synthesis of empirical research on undergraduate and graduate women of color in science, technology, engineering, and mathematics. Harv Educ Rev 81:172–209.
16. Furnham A, Reeves E, Budhani S. 2002. Parents think their sons are brighter than their daughters: Sex differences in parental self-estimations and estimations of their children's multiple intelligences. J Genet Psychol 163:24–39.
17. Kirkcaldy B, Noack P, Furnham A, Siefen G. 2007. Parental estimates of their own and their children's intelligence. Eur Psychol 12:173–180.
18. Robinson-Cimpian JP, Lubienski ST, Ganley CM, Copur-Gencturk Y. 2014. Teachers' perceptions of students' mathematics proficiency may exacerbate early gender gaps in achievement. Dev Psychol 50:1262.
19. Henriksen EK, Dillon J, Ryder J. 2015. Understanding student participation and choice in science and technology education. Springer.
20. Archer L, DeWitt J, Osborne J, Dillon J, Willis B, Wong B. 2012. "Balancing acts''': Elementary school girls' negotiations of femininity, achievement, and science." Sci Educ 96:967–989.
21. Moss-Racusin CA, Dovidio JF, Brescoll VL, Graham MJ, Handelsman J. 2012. Science faculty's subtle gender biases favor male students. Proc Natl Acad Sci 109:16474–16479.
22. Moss-Racusin CA, Molenda AK, Cramer CR. 2015. Can evidence impact attitudes? Public reactions to evidence of gender bias in STEM fields. Psychol Women Q 39:194–209.
23. Cotner S, Ballen C, Brooks DC, Moore R. 2011. Instructor gender and student confidence in the

sciences: a need for more role models. J Coll Sci Teach 40:96–101.

24. Kerkhoven AH, Russo P, Land-Zandstra AM, Saxena A, Rodenburg FJ. 2016. Gender stereotypes in science education resources: A visual content analysis. PLoS One 11:e0165037.

25. Ballen CJ, Salehi S, Cotner S. 2017. Exams disadvantage women in introductory biology. PLoS One 12:e0186419.

26. Cotner S, Ballen CJ. 2017. Can mixed assessment methods make biology classes more equitable? PLoS One 12:e0189610.

27. Harrison C, Tanner KD. 2018. Language Matters: Considering Microaggressions in Science. CBE—Life Sci Educ 17:fe4.

28. Grunspan DZ, Eddy SL, Brownell SE, Wiggins BL, Crowe AJ, Goodreau SM. 2016. Males Under-Estimate Academic Performance of Their Female Peers in Undergraduate Biology Classrooms. PLoS One 11:1–16.

29. Koester BP, Grom G, McKay TA. 2016. Patterns of gendered performance difference in introductory STEM courses. arXiv Prepr arXiv160807565.

30. Matz RL, Koester BP, Fiorini S, Grom G, Shepard L, Stangor CG, Weiner B, McKay TA. 2017. Patterns of Gendered Performance Differences in Large Introductory Courses at Five Research Universities. AERA Open 3:2332858417743754.

31. Ho DE, Kelman MG. 2014. Does class size affect the gender gap? a natural experiment in law. J Legal Stud 43:291–321.

32. Ballen CJ, Aguillon SM, Brunelli R, Drake AG, Wassenberg D, Weiss SL, Zamudio KR, Cotner S. 2018. Do Small Classes in Higher Education Reduce Performance Gaps in STEM? Bioscience.

33. Robnett R. 2013. The Role of Peer Support for Girls and Women in STEM: Implications for Identity and Anticipated Retention. Int J Gender, Sci Technol 5:232–253.

34. Stanich CA, Pelch MA, Theobald EJ, Freeman S. 2018. A new approach to supplementary

instruction narrows achievement and affect gaps for underrepresented minorities, first-generation students, and women. Chem Educ Res Pract 19:846–866.

35. Tai RH, Liu CQ, Maltese A V, Fan X. 2006. Planning early for careers in science. Life sci 1:0–2.

36. Maltese A V, Tai RH. 2010. Eyeballs in the fridge: Sources of early interest in science. Int J Sci Educ 32:669–685.

37. Wong B. 2016. Science education, career aspirations and minority ethnic students. Springer.

38. Andreassen R, Vitus K. 2016. Affectivity and race: Studies from Nordic contexts. Routledge.

39. Archer L, DeWitt J, Osborne J, Dillon J, Willis B, Wong B. 2012. Science aspirations, capital, and family habitus: How families shape children's engagement and identification with science. Am Educ Res J 49:881–908.

40. Cech EA, Waidzunas TJ. 2011. Navigating the heteronormativity of engineering: The experiences of lesbian, gay, and bisexual students. Eng Stud 3:1–24.

41. Cooper KM, Brownell SE. 2016. Coming out in class: Challenges and benefits of active learning in a biology classroom for LGBTQIA students. CBE-Life Sci Educ 15:ar37.