UNRAVELING GENDER DISPARITIES IN SCIENCE: ANALYSIS OF CONTRIBUTORSHIP AND LABOR ROLES

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Motivation. Rosalind Franklin (1920-1958) was an English chemist who made several important contributions to science before she died of ovarian cancer at the early age of 37. Despite her numerous scientific achievements, she is perhaps best known for her proximities to the Nobel Prize: for her work on the molecular structure of viruses for which her collaborator Aaron Klug was awarded the prize in 1982; and, more often referenced, her work on the discovery of the structure of DNA, for which her colleagues Francis Crick, James Watson, and Maurice Wilkins were awarded the Nobel Prize in 1962.

The story of the 1962 Nobel work is often heralded as a classic example of the "Matilda effect". The term, coined by sociologist Margaret Rossiter (1993) and named after Matilda Gage (1826-98), describes scholars who receive less recognition than expected or deserved, given their contributions to science. This effect is placed counter to Merton's (1968) "Matthew effect"[1], in which established scholars receive disproportionate credit due to mechanisms of cumulative advantage. In describing the Matthew Effect, Merton acknowledged the underside of the disproportionate allocation of rewards, but suggested that structurally this asymmetry could be overcome by lesser-known scholars communicating their ideas to those with the capital to disseminate it. However, as noted by Rossiter (1993), "such cynical advice—on how to capitalize on the prevailing system rather than to change it—can only increase the morale problems of postdoctoral fellows and others whose achievements are today routinely subsumed into the reputation of their team leader" (1993, p. 327).

Certain sociodemographic populations may be more likely than others to have their reputations "subsumed". For example, in 1981, Dr. Ruth Hubbard—who, in 1974, became the first female biology professor to be awarded tenure at Harvard University—remarked to *The New York Times* that: "Women and nonwhite, working-class and poor men have largely been outside the process of science making. Though we have been described by scientists, by and large we have not been the describers and definers of scientific reality. We have not formulated the questions scientists ask, nor have we answered them. This undoubtedly has affected the context of science, but it has also affected the social context and the ambience in which science is done" (cited from Marquard, 2016).

The place of women in science has been particularly well-studied by a variety of methods. For example, in our large-scale and contemporary analysis of the production of scientific articles, we found that men produced disproportionately more than women in nearly every country and the global production rates were approximately 30% female to 70% male (*Figure 1*). Other indicators tell a similar story of the lack of women in science and lack of rewards for those who are in science: from the perspective of receipt of citations (Larivière et al., 2013), receipt of funding (Ley & Hamilton, 2008), production of patents (Sugimoto, Ni, West, & Larivière, 2015), and size of salaries (Shen, 2013). In each of these areas, women

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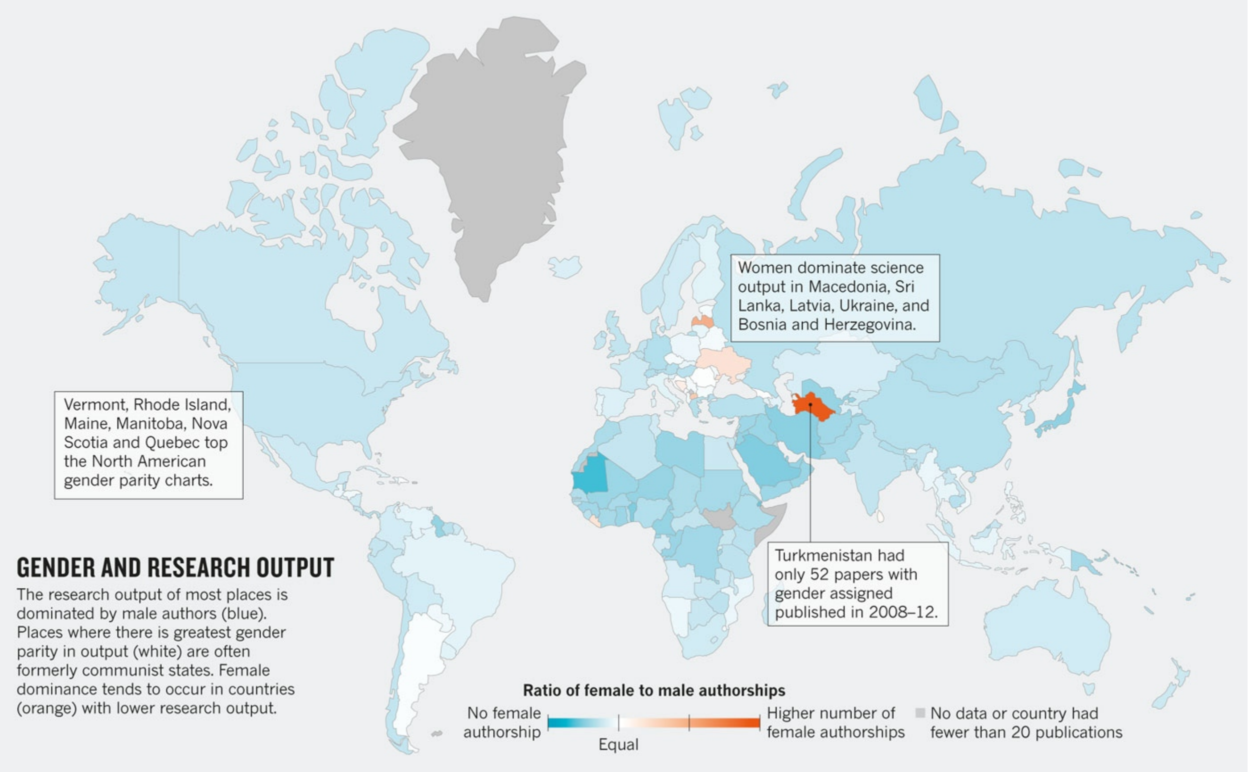
[1] The term comes from the Biblical gospel of Matthew: "For whomsoever hath, to him shall be given, and he shall have more abundance; but whomsoever hath not, from him shall be taken away even that he hath (13:12)."

have been shown to be persistently and progressively underrepresented and undervalued despite decades of policies aimed at equalizing the playing field.


GENDER AND RESEARCH OUTPUT

The research output of most places is dominated by male authors (blue). Places where there is greatest gender parity in output (white) are often formerly communist states. Female dominance tends to occur in countries (orange) with lower research output.

Vermont, Rhode Island, Maine, Manitoba, Nova Scotia and Quebec top the North American gender parity charts.

Women dominate science output in Macedonia, Sri Lanka, Latvia, Ukraine, and Bosnia and Herzegovina.

Turkmenistan had only 52 papers with gender assigned published in 2008–12.

Figure 1. Ratio of female to male authorships, by country. Source: Larivière, V., Ni, C., Gingras, Y., Cronin, B., & Sugimoto, C.R. (2013). Global gender disparities in science. Nature, 504(7479), 211-213.

The OECD and other governmental organizations routinely collect data on the size and composition of the scientific workforce: demonstrating the relative rate of production of highly skilled female and male laborers in the workforce (e.g, OECD, 2006). Yet, these statistics merely indicate the amount of women and do not provide an indication of their contributions to science. Information on labor roles in science could yield greater insights into not only disparities in production, but also disparities in the receipt of awards and resources.

The story of Rosalind Franklin and the discovery of the structure of DNA may serve as a useful anecdote into these disparities. There are several accounts of the interactions among Franklin, her doctoral student Raymond Gosling, and the three colleagues who eventually were awarded the Nobel Prize: Watson, Crick, and Wilkins. These accounts describe the sequence of events in which information was presented or shared, the dismissiveness of Watson towards Franklin in his memoir, and the animosity among the group (Cobb, 2015). However, what most accounts seem to overlook is the relationship between the allocation of credit and the type of labor employed.

In 1953, *Nature* published a set of three articles (*Figure 2*), generally understood as those which contributed to our understanding of the structure of DNA. The first article was authored by James Watson and Francis Crick. This article was highly theoretical and contained what they called a “purely diagrammatic” figure. The authors acknowledged the contributions of their colleagues, stating that the ideas behind the paper were “stimulated by a knowledge of the general nature of the unpublished experimental results and ideas of Dr. M.H.F. Wilkins, Dr. R.E. Franklin, and their coworkers" (cited from Sugimoto & Larivière, 2016). The second article was a data-driven report, authored by Maurice Wilkins and two other colleagues. The final article was authored by Franklin and Gosling. This article was much more analytical in nature and contained "Photo 51": a famed X-ray diffraction pattern credited for its precision and contribution to the discovery.[2]

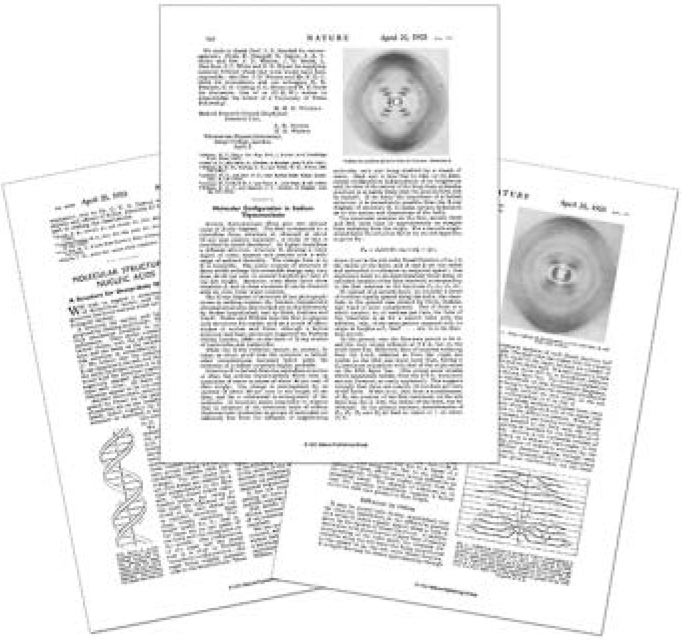


Figure 2. Set of three Nature papers, published together in 1953, which together served to reveal the structure of DNA. The top photo contains Photo 51. Source: Sugimoto, C.R. & Larivière, V. (2016). Perspectives: Giving credit where it is due. C&EN, 94(35), 32-33.

It is well-known that Franklin's data and Gosling's image were critical for Watson and Crick's theoretical advances. Yet, the accolades for the discovery went to Watson and Crick rather than Franklin and Gosling. Accounting for this disparity with gender alone obscures a critical distinction in the relationship between labor roles and rewards in science. That is, it may be that Franklin was undervalued in the contribution not due to her sex, but rather due to her type of contribution. To address this systematically, we need to create indicators that go beyond proportionality: that is, beyond the production of people or papers or the proportion of women in certain capacities. What is needed in an indicator that describes not only *how many*, but also, *in what ways* women contribute to science.

Specifically, we propose a novel indicator of gender in science focusing on labor roles, rather than counts of production. This provides a better indication not only in how women are contributing to science, but the ways in which the scientific system, generally, and the organization of scientific teams, specifically, may hinder or promote the advancement of women in science.

Contributorship. Authorship is at the heart of the scholarly communication system. It allows for the attribution of credit as well as the assignation of responsibility for the underlying work. Conceptually, authorship serves as a proxy for contribution to scientific work. The scholarly communication reward

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[2] J.D. Bernal, pioneer in X-ray crystallography, called it "amongst the most beautiful X-ray photographs of any substance ever taken" (Maddox, 2003).

system pivots on this notion: authorship denotes contribution to a piece of work, which is rewarded by the associated productivity and impact metrics assigned to the publication. In this way, authorship serves as symbolic capital in the academic reputation economy and drives several key science indicators.

This conceptualization, however, assumes both a shared understanding of the capital authorship provides as well as an implication that authorship does, in fact, indicate contribution to the work that is presented. Historical notions of authorship—that is, penning the words of the articles—align with this conceptual model. However, the model has been challenged in recent years by "hyperauthorship" (Cronin, 2001)—that is, the massive increase in authors listed on a byline of journal articles. For example, a 2015 paper in High Energy Physics listed more than 5000 authors, setting the record for the largest number of contributors to a single article (Castelvecchi, 2015). This article was 33 pages in length—the substance of the article was nine pages; the remaining 24 pages were used to list the names and affiliation of the 5154 authors, mostly in alphabetical order. The contribution of each of these authors to the substance of the paper is suppressed by merely listing on a byline; the way in which these authors labored is unknown.

The increasing number of authors per paper observed in all disciplines (Larivière et al., 2015) is in part due to the growing complexity and interdisciplinary of research, but it also demonstrates increasing recognition of various roles, such as those performed by "invisible technicians" in science (Shapin, 1989). By placing all those who contributed to a piece of research on the byline, we acknowledge that authorship—the coin of the academic realm—is a currency that should be provided to all those who labor in science, doctoral students (like Gosling) and established researchers alike. However, as authorship lists increase, there is greater emphasis placed on first and last authors, as these are typically the dominant authorship roles, associated with the highest levels of contribution (Larivière et al., 2016). Given that women garner fewer of these coveted spots (Filardo, 2016) and are currently underrepresented in the production of scientific articles (Larivière et al., 2013), their contributions to science may remain suppressed and undervalued.

Furthermore, the lack of an explicit relationship between labor and authorship has many severe consequences for the knowledge economy. First, there have been gross abuses in terms of fraudulent authorship practices, with rising rates of ghost and honorific authorship (Sismondo, 2009). In parallel, we have witnessed an increased number of incidences of retractions within science. Within the biomedical sciences, for example, studies have shown that nearly 20% of sampled articles have examples of honorific authorship and 10% are associated with ghost authorship (Wislar et al., 2011; Flanagin et al., 1998). Though these are not necessarily causal, they may be symptomatic of a widening distance between the labor of science and the crediting of it. This distancing leads to pernicious effects on scholarship and the scientific workforce: causing widespread goal displacement as well as injustices in the crediting of scientific labor. It has been argued that the present scholarly communication system rewards a "taste for publication" over a "taste for science" (Osterloh & Frey, 2015). Contributorship indicators, by examining more closely what constitutes labor in science and how it translates to authorship, will begin to unravel this system. This deeper analysis will allow us to construct possible interventions that can incentivize behavior more aligned with the values and principles of scientific work.

The International Committee of Medical Journals Editors (ICMJE) attempted to address these concerns with a statement on specific requirements for the attribution of authorship, first published in 1988. This statement provided three criteria that all of which must be met for someone to be considered an author on the paper, to which a fourth criteria was added in 2013[3]. These include: “1) substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; AND, 2) drafting the work or revising it critically for important intellectual content; AND, 3) final approval of the version to be published; AND, 4) agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved” (ICMJE, 2014). Despite these concerns, fraudulent authorship practices have not been curbed. Furthermore, these requirements did not address the distance between labor and authorship in an era where scientific work is highly specialized and distributed. This begins to, but does not fully address, unethical practices and injustice in allocating rewards to those who labor in science.

More recently, The Academy of Medical Sciences (2016) acknowledged the discontinuities in our current reward system, arguing for better delineating of individual contribution and adoptions of practices which equitably credit collaborative work. This resonates with Rennie and colleagues’ (1997) proposal, nearly 20 years ago, for a “radical change” in scholarly communication, moving from authorship (i.e., names on a byline) to contributorship (i.e., listing the contributions of each individual to the scholarship). Some journals, such as those by the Public Library of Science (*PLOS*), have adopted contributorship models as a supplement to the traditional byline. However, there has not yet been large-scale adoption of contributorship data, nor have we found ways to meaningfully integrate these data into our current assessment systems. The present proposal aims at both extracting and analyzing data, with gender and age as focal points in the analysis. To illustrate the potential utility of this indicator, we draw from the analyses of two previously published works: Macaluso et al. (2016) and Larivière et al. (2016).

Methods. All articles published by PLOS are available on the PLOS website in XML format. For our analysis, it was necessary to draw additional information from the Thomson Reuters’ Web of Science (WoS) indexes, including the Science Citation Index Expanded (SCIe), the Social Science Citation Index (SSCI), and the Arts & Humanities Citation Index (AHCI). We downloaded the full text of the articles and matched these to the Web of Science metadata, using the DOI as the unique identifier for integration. In total, 94,879 PLOS articles published between 2008 and 2013 were downloaded and matched to WoS records. Of these, contributorship data was only available for 87,002 articles. Therefore, these served as the basis for our contributorship analysis.

There were nearly 21,000 unique contribution labels associated with authors within PLOS. Therefore, a significant amount of work went into cleaning the data in order to merge semantically identical contribution types and to identify the most common contributions (for more on this process, see Larivière et al., 2016). In sum, the contribution types can be roughly categorized in five ways: 1) analyzed the data, 2) conceived and designed the experiments, 3) contributed reagents/materials/analysis tools, 4) performed the experiments, and 5) wrote the paper. Each author can be assigned to one or more of these roles, some roles can be omitted if irrelevant, and additional contribution types can be noted. *Table 1* demonstrates the number and percentage of articles and authorships associated with each of these types of contributions.

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[3] http://www.icmje.org/news-and-editorials/new_rec_aug2013.html

Contribution	Articles N	Articles %	Authorships N	Authorships %
Analyzed the data	85,900	98.7%	320,080	50.6%
Conceived and designed the experiments	85,406	98.2%	288,765	45.6%
Contributed reagents/materials/analysis tools	64,444	74.1%	220,331	34.8%
Performed the experiments	82,811	95.2%	311,679	49.3%
Wrote the paper	86,517	99.4%	287,796	45.5%
Other (20 243)	*15,900*	*18.3%*	*79,978*	*12.6%*
N distinct papers	87,002	100.0%	632,799	100.0%

Table 1. Number and percentage of articles and authorships (author-paper combinations) by type of contribution. Source: Larivière, V., Desrochers, N., Macaluso, B., Mongeon, P., Paul-Hus, A., & Sugimoto, C.R. (2016). Contributorship and division of labor in knowledge production. Social Studies of Science, 46(3), 417-435.

To further aid in analysis, we also assigned papers to a discipline, drawing upon the method developed by Waltman and van Eck (2012) and estimated the academic age of the authors, using the algorithm developed by Caron and van Eck (2014), which uses the age of first publication as a proxy for the academic age. To analyze gender contributions, we used the methods and algorithm described in Larivière et al. (2013). Gender could not be identified for all authors; therefore, the gender analysis focuses on a subset of 85,260 articles from the PLOS corpus (for more details on data cleaning and processing, see Macaluso et al., 2016). This processing allowed us novel insights into the differing gender roles in scientific production, controlling for variables such as disciplines, author order, academic age, discipline, team size, and country of author.

Results. In our analysis of more than 600,000 contributorship statements across nearly 90,000 articles published in *PLOS*, we were able to begin to clarify the link between authorship and labor roles (Larivière et al., 2016). One of the most illuminating results was on the bifurcation of conceptual and technical work within research: that is, that those who are performing the actual experimentation are often isolated from design and writing of the paper (*Figure 3*).

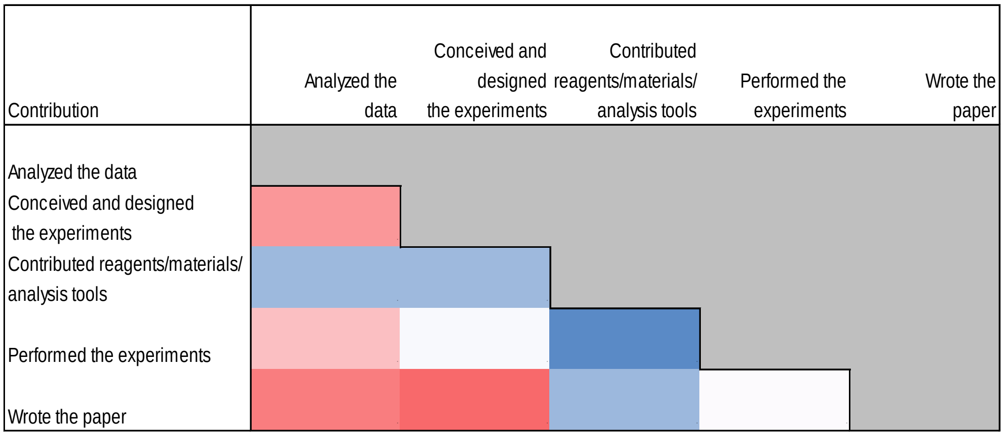

Figure 3. Association between contributions (red denotes a strong association, blue indicates a lack of association, and white indicates neutrality. Source: Larivière, V., Desrochers, N., Macaluso, B., Mongeon, P., Paul-Hus, A., & Sugimoto, C.R. (2016). Contributorship and division of labor in knowledge production. Social Studies of Science, 46(3), 417-435.

We also found several invariant relationships between some dominant authorship roles and contributorship tasks, with first authors contributing to the highest proportion of contributions and the middle authors performing the fewest contributions. Last authors contributed in more ways than middle authors, but far fewer than first authors. However, across all disciplines, the majority of authors contributed to fewer than four contributions, reinforcing the distributed approach to contemporary scholarship (*Figure 4*).

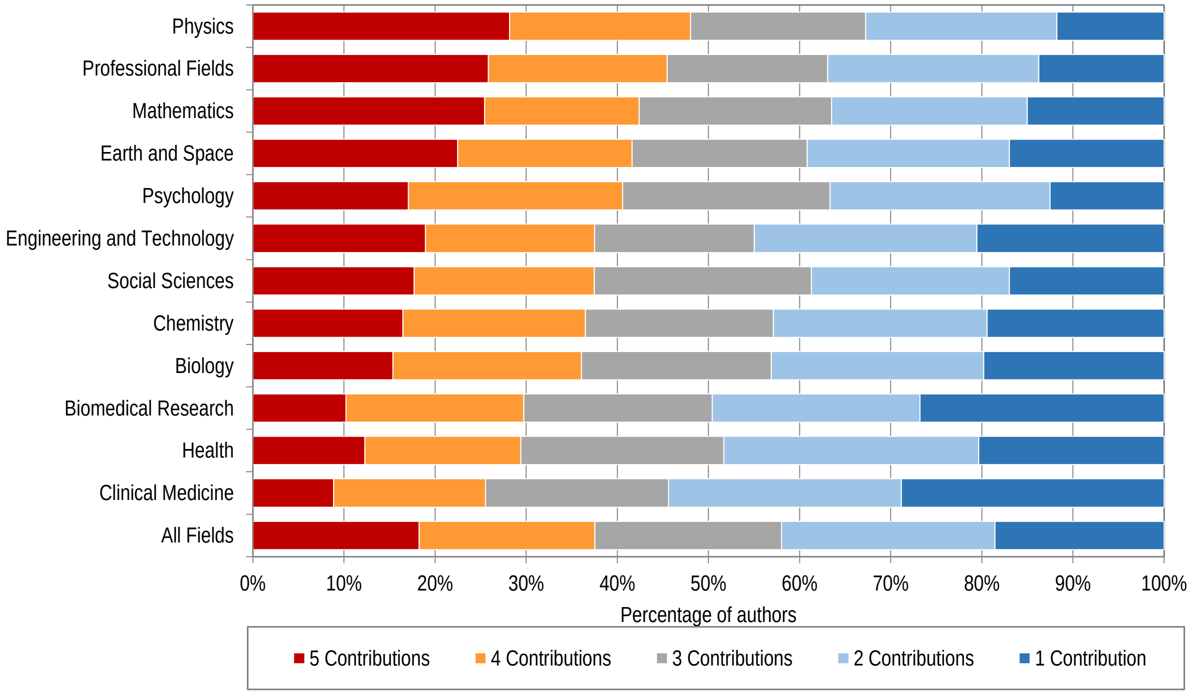

Figure 4. Distribution of authors as a function of their number of contributions, by discipline. Source: Larivière, V., Desrochers, N., Macaluso, B., Mongeon, P., Paul-Hus, A., & Sugimoto, C.R. (2016). Contributorship and division of labor in knowledge production. Social Studies of Science, 46(3), 417-435.

Type of labor was not independent from the sociodemographic characteristics of researchers, such as age (Larivière et al., 2016) and gender (Macaluso et al., 2016). As shown in *Table 2*, research design, contribution of resources, and writing tended to be associated with older scholars, on average. Younger scholars were more likely to be associated with performing the experiments.

Contribution	Mean age
Conceived and designed the experiments	13.2
Contributed reagents/materials/analysis tools	12.7
Wrote the paper	12.6
Analyzed the data	10.5
Performed the experiments	6.8

Table 2. Mean academic age of authors (time since first publication) associated with contribution type. Source: Larivière, V., Desrochers, N., Macaluso, B., Mongeon, P., Paul-Hus, A., & Sugimoto, C.R. (2016). Contributorship and division of labor in knowledge production. Social Studies of Science, 46(3), 417-435.

Our analysis also revealed several gendered ways in which scientific research is performed, based on contributorship data. A regression analysis, controlling for all other variables, demonstrated that women are significantly more likely to be associated with experimentation; whereas men were significantly more likely to be associated with all other tasks and particularly with the contribution of resources. This presents a severely distorted system, in which men's authorship is associated with resource allocation and women's with the performance of the scientific work. This holds true, even when analyzing by the gender of the corresponding author (*Figure 5*).

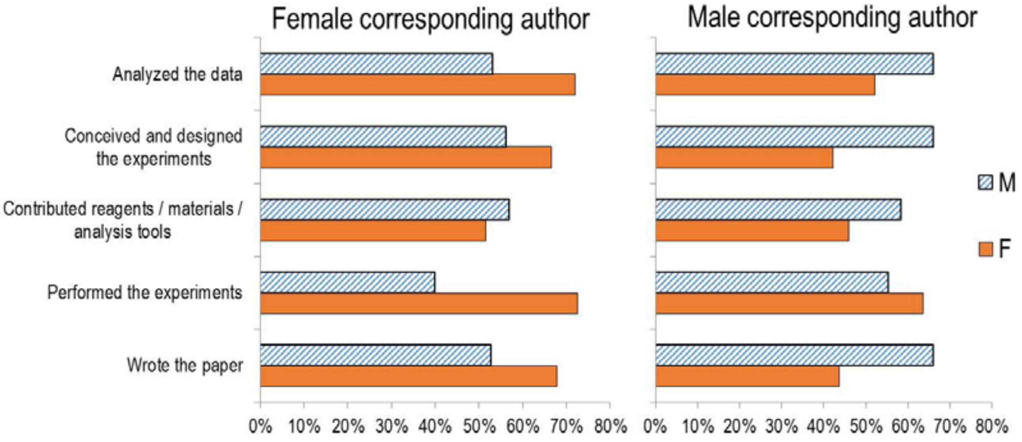

Figure 5. Proportion of male and female authors contributing to each labor role, by gender of corresponding author (top) and gender of first author (bottom). Source: Macaluso, B., Larivière, V., Sugimoto, T., & Sugimoto, C.R. (2016). Is science built on the shoulders of women? Academic Medicine.

One can also examine the distribution of roles, by the size of the team. As *Figure 6* demonstrates, the proportional contribution for most tasks decreases as team size increases. However, while there are significant differences in distribution by the gender of the corresponding authors as well as by the members of the team, a higher share of women authors performing the experiments is consistently observed.

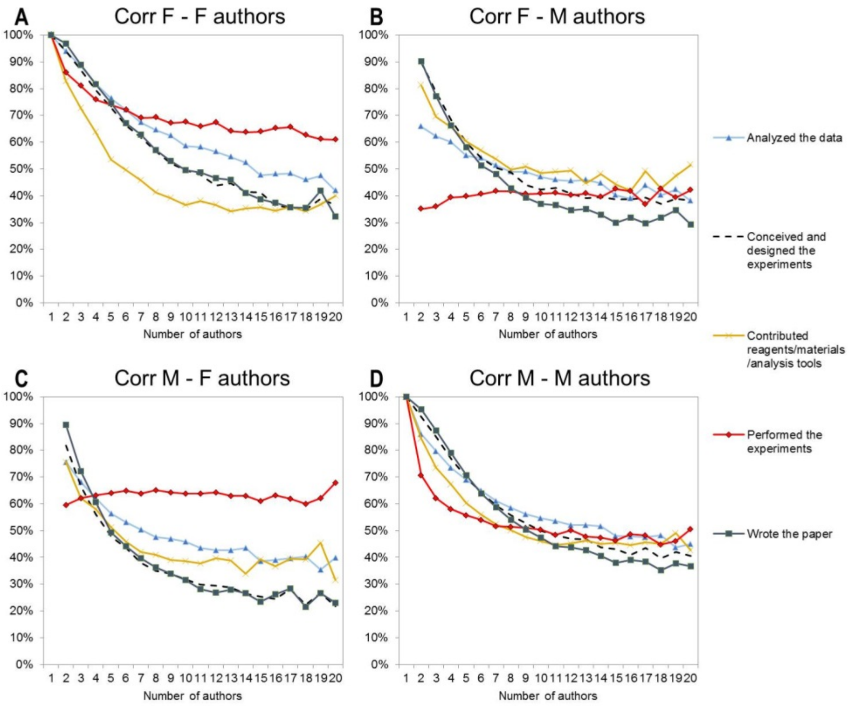

Figure 6. Proportion of male and female contribution as a function of the total number of authors, by gender of corresponding author. Source: Macaluso, B., Larivière, V., Sugimoto, T., & Sugimoto, C.R. (2016). Is science built on the shoulders of women? Academic Medicine.

One might assume that the finding relating to women and experimentation is an artifact of age. However, as the data demonstrates, in the case of experimentation, there remains a clear and persistent gender gap, even when aging is taken into account. For the other tasks, the gender gap because less pronounced as women academically age (*Figure 7*).

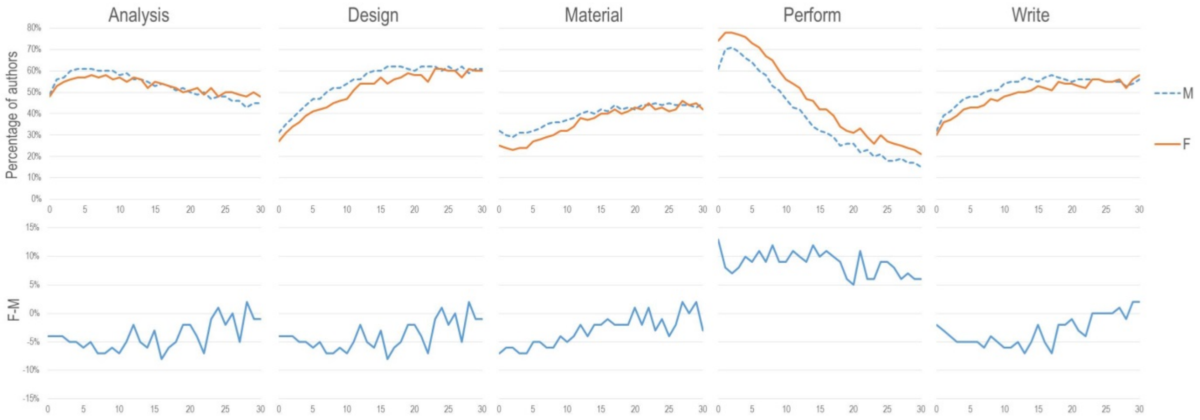

Figure 7. (Top) Proportion of male and female authorships (y-axis) associated with contributorship by career age (x-axis). (Bottom) Difference in female to male contributorship (y-axis) by career age (x-axis). Source: Macaluso, B., Larivière, V., Sugimoto, T., & Sugimoto, C.R. (2016). Is science built on the shoulders of women? Academic Medicine.

Policy implications. Our proof-of-concept exercise demonstrated that there is a significant amount of information that can be captured from contributorship data, to inform our understanding of gender disparities in science, as well as other variables. Given the significant differences in authorship practices across disciplines (Biagoli & Galison, 2003; Pontille, 2004), contributorship provides the opportunity for more systematic and standardized way of evaluating contribution than authorship. Policies that examine team structure and the distribution of labor across teams, for example, may be more effective than previous policies focused on proportional representation. We urge the OECD, therefore, to advocate for the construction of contributorship indicators to supplement the widespread use of authorship indicators in measuring research.

Furthermore, our research demonstrates that there are significant gender disparities in contemporary labor roles in science, with women more likely to earn authorship from performing experimental work, while men are typically associated with conceptual work and contribution of resources (Macaluso et al., 2016). Some may argue that this is merely an artifact of the leadership roles in science and will dissipate when there are more women as heads of labs. However, the disparity holds when controlling for academic age and gender of corresponding author: even when they become senior researchers, women remain more likely to contribute to experiments than men, which suggest that disparities are perpetuated with certain roles developed in undergraduate, graduate, and early career years in junior years that are carried on throughout the academic lifecycle.

Franklin died before the Nobel Prize was jointly awarded to Crick, Watson, and Wilkins. We are not in the position to argue whether her sex would have kept her from joining that prized triad—replacing one of the men, as the prize is capped at three individuals— were it not for her untimely death. Rather, it bears questioning whether her *contribution* would have been recognized as sufficient. Our work suggests that certain contributions are more lucrative, from the perspective of academic capital, and these are more likely to be associated with male scientists. Therefore, either the distribution of labor or the reward system of science must be reexamined. If we maintain the status quo individuals who dedicate their work to experimentation and the construction of high quality datasets will continue to remain undervalued and are more likely to leave the scientific system. Furthermore, the relegation of certain segments of the population to particular types of contributions diminishes potential for creativity and innovation throughout the research process. Contributorship indicators would serve to make transparent these disparities.

However, there are several critical limitations to the present status of contributorship data. First and foremost, they are limited to a few journals, with PLOS being the only large-scale platform from which they can be easily extracted. This leads to a disciplinary bias in the analysis, in that the journals are predominately in the biomedical domain. Furthermore, as we noted, there were nearly 21,000 distinct labels of contributions, making it difficult to parse and analyze. A new development may alleviate this complexity: as of 2016, PLOS adopted the CREDIT taxonomy for authorship. This will provide a standard set of contributions with which authors will identify (Atkins, 2016). As PLOS argued, “More finely grained information will help make the ordering of authors less important and will facilitate a shift in focus for tenure and promotion committees—and other evaluators—away from how many times an individual is a first-or last-named author and toward their specific contributions to the scholarly record” (Atkins, 2016). Were other platforms to adopt this taxonomy and make their data available in XML format, there would be a greater ability to create globally comparable data on contributions to science.

The lack of contributorship data is a critical limitation in creating a more nuanced indicator of the labor roles performed in science. In order to construct data-driven policies towards gender equality, it is imperative that the reporting of contributorship become standard scientific practice. The OECD is well-positioned to advocate for this and to create infrastructure that both facilitates data collection and aggregates these data in way that can be easily accessed by science policy makers. These data provide a window not only into gender inequality but can, when matched when demographic data, also inform our understanding of other potential biases in the scientific system.

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