




## Supporting academic equity in physics through citation diversity

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While gender disparities in the science, technology, engineering, and mathematics (STEM) disciplines are widely noted, the citation gap is still understudied and awareness remains low. Here, we address citation inequity in physics and describe individual and collective mitigation initiatives, including the citation diversity statement.

Recent work in several fields of science has identified a bias in citation practices such that papers by women scholars and scholars of color (and therefore also those at the intersections of these categories) are under-cited relative to the number of such papers in the field. These fields include astronomy<sup>1</sup>, economics<sup>2</sup>, neuroscience<sup>3,4</sup>, communications<sup>5</sup>, international relations<sup>6,7</sup>, cognitive science<sup>8</sup>, and medicine<sup>9</sup>. Undercitation means that the actual proportion of citations for papers led by underrepresented scholars is less than what would be expected if gender, race, or ethnicity did not play a role in citation practices<sup>8,10</sup>. The undercitation of underrepresented scholars holds even when the base rates of expected citations account for the year of publication, the journal in which the paper was published, the number of authors on the paper, whether the paper was a review article or an empirical article, and the seniority of the paper's first and last authors<sup>3-5,8,11</sup>. The effect also holds both in lower and higher impact papers, and is not explained by subfields that may be more men- and white-dominated<sup>3,4</sup>. These data demonstrate that inequity is prevalent in science<sup>10</sup>.

Why is the undercitation of underrepresented scholars important? Sara Ahmed, working at the intersection of feminist, queer, and race studies, characterizes citations as “academic bricks”<sup>12</sup>. These bricks are one of the basic building blocks of academic careers and fields of inquiry. As building blocks of careers, citations are used to measure a scholar's success, granting access to post-doctoral or permanent positions, promotions, higher salaries, funding, collaborative opportunities, invitations to speak at conferences, and so on. Undercitation can therefore have negative consequences for a scholar's career advancement<sup>13</sup>—hindering visibility, diminishing perceived prestige, and stalling promotion. As building blocks of fields of inquiry, citations map the scholarly work in each discipline. Decreased engagement with the work of underrepresented scientists, therefore, can impact the purview and the progress of science<sup>14</sup>—narrowing the space of inquiry and decrementing the scope of questions considered. As academic bricks, then, citations can build a more diverse scientific community or erect walls of exclusion. Importantly, bricks do not just fall into place; they are placed<sup>12</sup>. If we are actively searching for ways to be more inclusive, more equitable, and to value good scientific ideas on their own terms<sup>15</sup>, it behooves us to cultivate a conscientious citation practice. In reasoning through his own responsibility to cite equitably in scholarly writing, philosopher John Lysaker

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writes that, “a genuinely reflective, deliberative approach to [the] praxis”<sup>16</sup> is necessary. The deliberate writer anticipates the stakes of citation imbalance and chooses to cite—and to build their reference lists—differently.

Until recently, it was not yet clear whether citation imbalances existed in physics. However, data is now available to suggest that citation inequities exist across contemporary physics subfields, including astronomy and astrophysics, soft matter, biophysics, condensed matter, high energy, nanoscience, nuclear, atomic, molecular, and optical physics<sup>11</sup>. In the reference lists of 1.07 million papers published in 35 journals over the last 25 years, probabilistic estimates of the gender makeup of cited papers were obtained using a name-based approach. Pervasive under-citation of papers written by at least one woman (first or last) author were observed, using a null model that predicts the gender makeup of reference lists given certain characteristics of cited papers, including author seniority, year of publication, and journal. This citation gap varies according to who is citing, with man-authored papers showing a citation preference toward man-authored papers that has grown from 1995 to today, and woman-authored papers showing a citation preference toward woman-authored papers that has diminished over this same time period. The overall effect is a citation gap in favor of men that is growing with time, due to the predominance of men in physics. This gap also varies according to where papers are published, and is most egregious for papers in general interest physics journals, including *Physical Review Letters*, *Nature Physics*, *Review of Modern Physics*, *Physical Review X*, and *New Journal of Physics*. Interestingly, citation imbalances are also particularly marked when authors are citing papers in a different subfield or on which they were not a co-author. This citation gap for less familiar papers is notable, and characteristic of man author teams but not women author teams. This large dataset also reveals that the citation gender gap is greater for journals that publish fewer papers by women. The gap is also greater for papers that have shorter reference lists, and mitigated for papers

Recent work in several fields of science has identified a bias in citation practices such that papers from women and other minority scholars are under-cited relative to the number of such papers in the field [-]. Here we sought to proactively consider choosing references that reflect the diversity of the field in thought, form of contribution, gender, race, ethnicity, and other factors. First, we obtained the predicted gender of the first and last author of each reference by using databases that store the probability of a first name being carried by a woman [-]. By this measure (and excluding self-citations to the first and last authors of our current paper), our references contain 54.83% woman(first)/woman(last), 17.46% man/woman, 13.42% woman/man, and 14.29% man/man. This method is limited in that a) names, pronouns, and social media profiles used to construct the databases may not, in every case, be indicative of gender identity and b) it cannot account for intersex, non-binary, or transgender people. Second, we obtained the predicted racial/ethnic category of the first and last author of each reference by databases that store the probability of a first and last name being carried by an author of color [-]. By this measure (and excluding self-citations), our references contain 7.78% author of color (first)/author of color(last), 12.58% white author/author of color, 19.05% author of color/white author, and 60.6% white author/white author. This method is limited in that a) names, Census entries, and Wikipedia profiles used to make the predictions may not be indicative of racial/ethnic identity, and b) it cannot account for Indigenous and mixed-race authors, or those who may face differential biases due to the ambiguous racialization or ethnicization of their names. We look forward to future work that could help us to better understand how to support equitable practices in science.

**Fig. 1 Citation diversity statement for the present comment.** Like a paper, a citation diversity statement includes motivation (highlighted in purple), method (blue), results (green), limitations (yellow/orange), and future vision (red)<sup>18</sup>. The symbol ‘[-.]’ indicates references to support the statements made, which are updated regularly as evidence accrues and methods are extended. The numbers reported here reflect the reference list of this comment. In addition to these algorithmic results, we note that we also cite at least 3 trans and/or nonbinary scholars.

that have longer reference lists. The results underscore the complexity with which gender disparities manifest in scientific publishing in physics, marking citations as a key space harboring those disparities.

In this perspective, we provide physicists with new information about the ways in which they can deliberately support academic equity through citation diversity. We begin by describing recent efforts to address citation disparities using a so-called Citation Diversity Statement, and then canvas associated initiatives largely pioneered in the biological sciences. Subsequently, we move to a broader discussion regarding not just *who* we are citing, but also *how* we are citing them, in our papers, in our conversations, and in our other academic activities. Citation diversity—along the lines of gender, as well as race, ethnicity, and so on—matters for the flourishing of our physics community, and for our potential to appeal to and support the best minds of the future.

### Citation diversity statements and initiatives

In response to the existing data, individual researchers are increasingly evaluating (and actively re-balancing) the gender, racial, and ethnic makeup of their reference lists before submitting their papers to preprint servers, conferences, or journals for peer review. Benchmark ratios of author demographics are increasingly available for various disciplines, providing investigators with rough proportions to meet or exceed. To determine the author gender, race, and ethnicity of their current paper’s reference list, investigators are using a variety of approaches including (i) personal knowledge of authors, (ii) targeted Google searches (e.g., identifying an author’s pronouns or self-attested race/ethnicity on professional homepages), and (iii) automated tools to probabilistically predict demographic characteristics from an author’s first and last names<sup>17</sup>. When these assessments show that a current reference list is (or is likely to be) imbalanced, the investigator takes the opportunity to educate themselves further about the relevant work of underrepresented scholars. Often, this self-education is particularly needed in relation to the work of younger faculty, as a significant proportion of current scholars with marginalized identities have been hired in the last decade.

To raise awareness and to transparently report on the balance of their reference list, investigators are appending a citation diversity statement (CDS) to their papers. A CDS typically states: (i) the importance of citation diversity, (ii) the percentage breakdown (or other diversity indicators) of citations in the paper, (iii) the method by which percentages (or other indicators) were assessed and its limitations, and (iv) a commitment to improving equitable practices in science<sup>18</sup>. In Fig. 1, we present the CDS for this comment and explain the various parts composing it. The use of the CDS is growing, and papers with CDSs have now been published in at least 32 different journals. The discipline general journals that have published investigator’s CDSs include the *Proceedings of the National Academy of Sciences*, *Science Advances*, *Nature Communications*, and *Scientific Reports*. The discipline specific journals that have published investigator’s CDSs include several in the Nature family (e.g., *Nature Machine Intelligence*, *Nature Biomedical Engineering*, *Nature Reviews Neuroscience*, *Nature Neuroscience*, *Communications Biology*) as well as others, with notable leadership from the biological sciences. Examples include *Biological Psychiatry*, *Journal of Neuroscience*, *Journal of Tissue Engineering*, *Journal of Vision*, *ACS Catalysis*, and *Annals of the International Communication Association*. While the CDS is widely adopted in the life sciences and by interdisciplinary journals, physics journals and the STEM community more broadly have been slower to actively support citation diversity awareness.

Building on the efforts of investigators who submit papers with CDSs for publication, journals are beginning to create a pre-defined space for CDSs in their paper format, similar to the space for the “Acknowledgments” or “Data and Code Availability”. Cell has begun including a dedicated inclusion and diversity form to gather information on the diversity of study subjects, authors, and contributors, with the option to include a statement in the paper<sup>19</sup>. The *Journal of Cognitive Neuroscience* now requires a CDS in the [submission guidelines](#), offers a [journal-specific tool](#)<sup>8</sup> to estimate the gender citation balance index (GCBI)<sup>20</sup>, and invites authors to report their GCBI in their CDS. Journals under the Biomedical Engineering Society now include an optional CDS, with guidelines on stating the motivation behind the CDS, the proportion of citations by gender and race/ethnicity, the methods and limitations, and steps taken to improve citation diversity<sup>21</sup>, while providing the following publicly available [journal-general tool](#)<sup>17</sup> as an example. In addition to these policy changes, journals such as *Nature Reviews Physics*<sup>22</sup>, *Nature Neuroscience*<sup>23</sup>, and *Brain*<sup>24</sup> have raised awareness through editorial pieces, and journals such as *Nature Neuroscience*<sup>25</sup>, *PLOS Biology*<sup>26</sup>, the *Journal of Neuroscience*<sup>27</sup>, *Nature Immunology*<sup>28</sup>, *Neuron*<sup>29</sup> and *Trends in Neurosciences*<sup>30</sup> have published essays and perspective pieces that contextualize the importance of citation diversity in the broader conversation about bias in academia. Through these pieces, we learn that biased citation practices do not stand alone, but conspire with many other factors such as biased hiring practices<sup>31</sup>, grant funding<sup>32</sup>, and perception of publication quality<sup>33</sup> to work against a diverse and equitable academic environment. However, increasing citation diversity, through the thoughtful construction and revision of reference lists, remains an effective means for individual and groups of scientists to both raise awareness and work together to increase equity.

### Beyond (and behind) the citation diversity statement

While its heart is qualitative and intentional, the linguistic center of the citation diversity statement is quantitative and numeric, allowing the investigator to statistically report the balance (or imbalance) of their reference list. As the CDS (or a similar technique) becomes habitual or even a matter of journal policy, a careful builder and deliberate writer might very quickly begin to worry they are simply playing a numbers game, trying to make the numbers work rather than actually engaging equitably with the work of other scientists. And what even is equitable engagement? Simply counting the number of citations to a particular demographic does not in itself capture—or address—the existing (in)equities of authorial value and standing. How, in what kind of sentence, what sort of paragraph, and which section does the investigator engage with the work of women scholars and scholars of color? Are the investigator’s citations to over-represented scholars personal and prominent (e.g., “So-and-so et al. provide evidence X, which is central to our hypothesis Y”)? Are the citations to women, especially women of color, scholars listed in a side comment (e.g., “see Refs. a-g for related work”), or treated as derivative of or merely a footnote to their more privileged counterparts? Does the investigator wrestle deeply with the ideas and data from underrepresented scholars, just as deeply and as thoughtfully as with those of over-represented scholars? Is the investigator familiar with the underrepresented scholar’s full body of work or one random article? Is that work central to the framing of the investigator’s argument in the introduction, or an extraneous example in the discussion?

For Sara Ahmed, citations are not only “academic bricks,” to be stacked and counted; they are also “paths”<sup>34</sup>. Citations are trails

of where the author has been and trails of where the reader might go. And, just as paths that are well-trodden are easiest to tread, so over-cited groups are easiest to cite. Instead of using citation as a technology of reproduction and a technique of selection to create and maintain a homogeneous discipline<sup>35</sup>, Ahmed recommends a different tack. The practice of citation diversification involves building new pathways through the network of scientific scholarship and inviting a wider set of companions to join you on the journey. It requires “conscious engagement” with the work and legacies of women scholars, scholars of color, Indigenous scholars, LGBT scholars, disabled scholars, first generation low income scholars, etc.<sup>36</sup>. Under space constraints, it involves deciding what to name and what to unname<sup>37</sup>, what to pick and what to “unpick”<sup>38</sup>. It involves learning how to hesitate and where to dig in. Citation equity is not achieved through a quick tweak before submission; rather it is the effect of everyday reading, thinking, talking, and teaching habits that consistently expand how the story of science is told. And those habits have crucial implications not only for STEM pipelines, but for the future of science as a whole.

Calls for equitable scholarly engagement have a long and eventful history. In 1993, Margaret Rossiter coined the term “Matilda effect” to describe the steady mis-attribution of women’s scientific contributions to their men colleagues<sup>39</sup>. The term honors Matilda J. Gage who identified the trend over 150 years ago<sup>40</sup>. In response to the specific undercitation of Black women, Christen Smith in 2017 founded the Cite Black Women project, which has since developed into a vibrant collective, with clear resolutions, a successful hashtag campaign, a podcast, and multi-tiered outreach initiatives<sup>41</sup>. Joining her voice to Lynn Bolles, Barbara Christian, and others, Smith insists that epistemic justice requires recognizing Black women’s contributions to the story of knowledge<sup>42–44</sup>. The costs of excluding these and other voices are high, especially for STEM pipelines. Exposure to and internalization of stereotypes regarding who can be a scientist<sup>45–48</sup> and what constitutes the act of doing science—as told through textbooks<sup>49–52</sup> and other means—have profound impacts on scientific performance<sup>53–55</sup> and interest<sup>54,56</sup> among women and girls. A crucial counterpoint to that erasure, as dramatized by the recent films *Hidden Pictures* and *Picture a Scientist*, are the counterspaces and counterstories that women, especially women of color, in STEM continue to create<sup>57,58</sup>. Citations are one way to tell those stories and make those spaces.

The story of science as an objective hunt for inalienable truths performed primarily by lone genius white men has pernicious effects not only for those aspiring to science, but also for well-established scientists who hold marginalized identities. And indeed, the perceptions and stereotypes of today become the scientific history of tomorrow, pointing toward a future (and a well-established past<sup>39</sup>) of erasure for scientists who are marginalized on the basis of gender, sexuality, race or ethnicity, class, or disability. As individuals and collectives, we have the ability and the responsibility to tell richer, more complete scientific stories to one another, thereby interrupting the historical trend of exclusion and hegemony. We can build a different future, and we can forge other paths to be traveled. Many efforts exist already<sup>59</sup> to contextualize scientific progress outside of the dominant narrative of white masculine European triumph<sup>60,61</sup>, including visibility platforms in print form<sup>62</sup> and online databases<sup>63–65</sup>, and much work remains to be done.

Acknowledgment of citation bias alongside the practice of citation diversity in individual scholarship and editorial practice is only one form of story-building, and we invite readers to consider other ways they can make visible the contributions of all scholars to the scientific endeavor<sup>66</sup>.

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P.Z., E.G.T., S.C.S., J.Z.K., and D.S.B. wrote the paper.

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The authors declare no competing interests.

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