ROBOTS AND SOCIETY



# Accelerating the pace of innovation in robotics by fostering diversity and inclusive leadership

**Daniela Macari[1,2]*, Alex Fratzl[3], Ksenia Keplinger[4]*, Christoph Keplinger[1,5,6]***

**Diverse and inclusive teams are not merely a moral imperative but also a catalyst for scientific excellence in robotics. Drawing from literature, a comprehensive citation analysis, and expert interviews, we derive seven main benefits of diversity and inclusion and propose a leadership guide for roboticists to reap these benefits.**

## INTRODUCTION

The field of robotics is highly interdisciplinary—spanning from mechanical and electrical engineering to materials science, computer science, neuroscience, and biology. In this regard, our robotics community is a champion of academic diversity. However, less recognized is the value of workforce diversity (members of different ethnicities, genders, ages, and life experiences, as well as different socioeconomic, parental, and disability statuses) comprising the robotics community, despite the literature indicating that team diversity paired with inclusive leadership drives disruptive innovation and creativity in the sciences (*1*–*14*). Promoting diversity and inclusion within research teams is not merely a moral imperative; it is a catalyst for facilitating cutting-edge research and accelerating progress in the field of robotics.

Here, we highlight existing scientific literature, analyze citation metrics of robotics papers over the past 25 years, reflect on our personal experiences and observations from working in a diverse and inclusive environment, and share insights from interviews with 10 established research leaders in robotics; therefrom, we outline seven main benefits of diversity and inclusion in robotics research (Fig. 1) and offer a guide for harnessing these benefits within the greater robotics community.

[1]Robotic Materials Department, Max-Planck Institute for Intelligent Systems, Stuttgart, Germany. [2]Computational Robotics Lab, ETH Zürich, Zürich, Switzerland. [3]Institute of Molecular and Clinical Ophthalmology Basel, Basel, Switzerland. [4]Organizational Leadership and Diversity, Max-Planck Institute for Intelligent Systems, Stuttgart, Germany. [5]Paul M. Rady Department of Mechanical Engineering, University of Colorado Boulder, Boulder, CO, USA. [6]Materials Science and Engineering Program, University of Colorado Boulder, Boulder, CO, USA.
*Corresponding author. Email: macari@is.mpg.de (D.M.); kkeplinger@is.mpg.de (K.K.); ck@is.mpg.de (C.K.)

## BENEFITS OF DIVERSITY AND INCLUSIVE LEADERSHIP IN ROBOTICS RESEARCH

### Improved performance and productivity

Team members tend to display higher motivation and commitment to their work in an atmosphere promoting inclusion, diversity, psychological safety, and a sense of self-value (*2*, *3*), leading to higher productivity within the team: Analyses of publications across different fields show that ethnically and gender-diverse teams publish a higher number of papers and have more citations per paper (*1*, *4*, *5*). To study the effect of diversity on "scientific impact" as measured by citations, AlShebli *et al.* (*1*) analyzed 9 million papers and 6 million scientists and found a strong correlation between ethnic diversity and number of citations. They used randomized baseline models and coarsened exact matching (a technique used to infer causality in observational studies) to establish ethnic diversity as one causal factor for scientific impact. We analyzed citation metrics of robotics papers over the past 25 years (for details, see the Supplementary Materials) with respect to gender diversity and found a positive correlation between gender-diverse authorship and citation performance: Publications with at least 25% female authors are significantly more cited and are more likely to be among the most-cited papers (Fig. 2). We note that in our analysis, we conducted a correlation-based study and focused on a single dimension of diversity; future research should explore additional dimensions of diversity and use techniques that can infer causality. In addition to improved citation performance and productivity, Allison Okamura (professor at Stanford University) further stated that having a diverse team has helped her secure research funding: "We can make really compelling arguments, and we have people who have first-hand experience and knowledge coming from different backgrounds. That's actually really helped us in obtaining research funding."

### Comprehensive problem-solving

Research challenges in robotics are complex and multifaceted. Diverse teams are better equipped to tackle issues from multiple angles, making use of a broader pool of methods and considering a wider array of potential solutions (*6*). Research shows that diverse groups of thinkers often outperform homogeneous groups of high-ability individuals in problem-solving and prediction-making tasks (*7*, *8*). Whereas homogeneous teams are more susceptible to groupthink, diverse teams are more likely to challenge each other's ideas, which leads to better outcomes when it comes to problem-solving (*6*). This matches the observations of Barbara Mazzolai (associate director at the Italian Institute of Technology), who stated that "[...] diverse teams bring rich perspectives because they can propose innovative solutions to complex problems in robotics."

### Disruptive innovation and creativity

A diverse team composition fosters unconventional ideas, which can ultimately lead to more disruptive innovation (*9*–*14*) and breakthroughs in robotics. Analysis of data from US PhD recipients from different disciplines across three decades indicates that demographically underrepresented researchers (such as gender and ethnic minorities) tend to produce higher rates of scientific novelty (*9*). A study using both experiments and survey data showed a link between team members with multicultural experience and enhanced team creativity (*10*).

Individuals from underrepresented backgrounds contribute with distinctive viewpoints, creative approaches, and unique personal interests that can enrich the research process; Allison Okamura says, "I get most of my ideas from my students [...]. Almost every new project comes about because a student has something in their personal background. Maybe they were knitting and got interested in knitting as a fabrication technique, and then that became a new fabrication method that we use in soft robotics. Maybe there's a student who is from a first-generation low-income background and recognizes that in that community, access to certain types of medical devices is really difficult or impossible, and so that inspires us to create designs that might be more effective in those communities."

### Broader applicability and relevance of research

Scientific discoveries made by diverse teams are more likely to address the needs of a broader segment of society, thus catering to a wide range of cultural and socioeconomic backgrounds and eventually leading to technologies with a broader societal relevance (*15*, *16*). Moreover, diversity of authors taps into different academic communities, which leads to a wider outreach of scientific results compared with papers written by nondiverse teams (*5*, *17*). "For me, where diversity is going to matter a lot in science, engineering, and robotics is being able to actually translate the work that we're doing in the lab back into the real world," said Jeremy D. Brown (assistant professor at Johns Hopkins University Whiting School of Engineering).

### Reduced bias in technology

Bias in robotics can influence how robots perceive, interpret, and respond to different groups of humans, potentially leading to unequal or harmful outcomes for certain ethnicities (*18*, *19*). This becomes particularly concerning when robots are used in sensitive environments like health care, public services, or law enforcement (*20*). Diverse groups of researchers, which better represent the diverse pool of users of robotics technologies, are better at identifying and mitigating biases in technology development and are more likely to consider ethical implications from various perspectives (*21*–*23*). Maartje de Graaf (assistant professor at Utrecht University) argued, "Technology is shaping our world. So, it's really important that all users from as broad a spectrum as possible should be able to give input on how technology will be developed in the future."

### Attraction and retention of talent

Diversity can be a powerful tool for attracting talent (*3*); in their experimental study, Avery *et al.* (*24*) found that job seekers with positive attitudes toward diversity are more likely to seek employment with organizations that value diversity. Academic institutions prioritizing diversity, equity, and inclusion have a competitive edge in the global market for academic talent (*25*)—ever more important in times of fierce competition from the private sector, where robotics professionals are highly sought after and well compensated. Promoting diversity and


**Fig. 1. The benefits of workforce diversity and inclusive leadership for robotics research.** Team diversity paired with inclusive leadership is a catalyst for cutting-edge research and a driver for broad applicability.

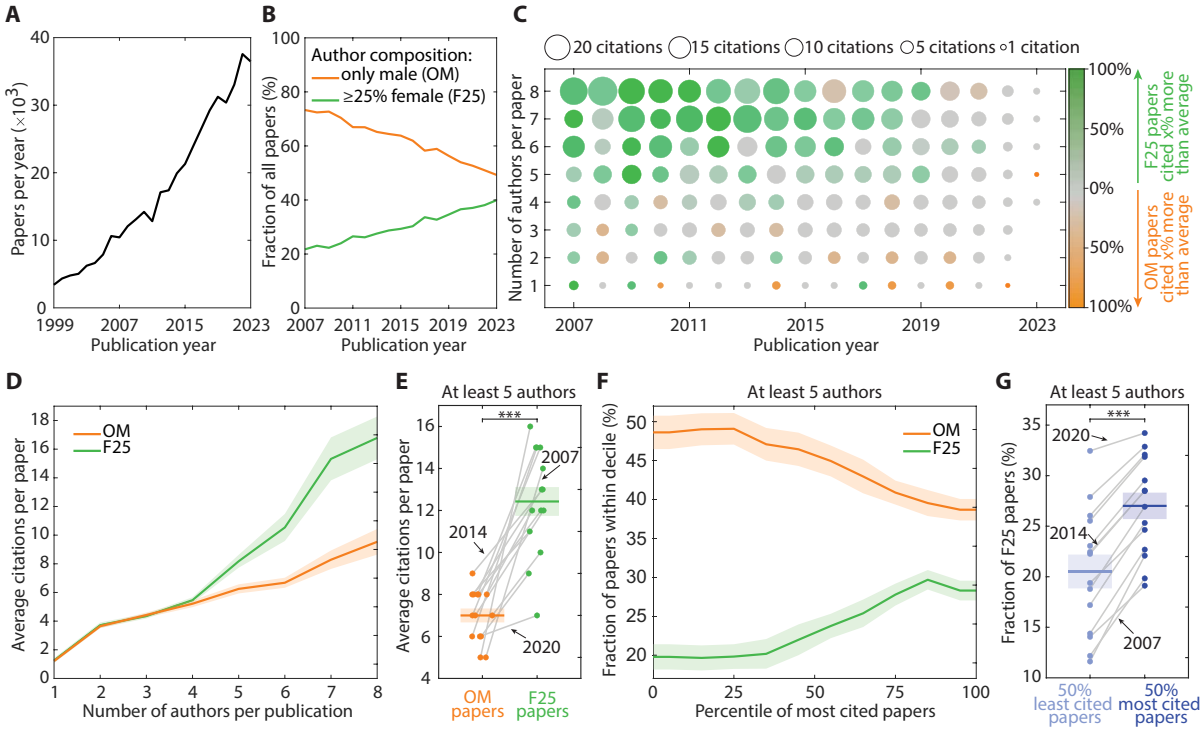


**Fig. 2. Citation analysis of robotics papers reveals a positive correlation between gender-diverse authorship and citation performance.** The gender of authors was determined using Genderize.io, a tool that assigns a gender to a first name with a certain probability; this probability was chosen to be 80% for the data presented here (for details on the statistical analysis, additional analysis regarding the geographic origin of papers, and limitations, see the Supplementary Materials). (**A**) The field of robotics has seen rapid growth over the past 25 years, with (**B**) a continuously increasing share of female authorship. (**C**) The average number of total citations for papers written in a given year increases with publication age, number of authors, and gender diversity. (**D**) Publications with at least 25% female authors (F25) and at least five authors per paper receive a higher average number of citations, (**E**) a trend that is consistently visible in every single year from 2007 to 2020. (**F**) F25 papers are more likely to be among the most-cited papers, (**G**) a trend that is consistently visible in every single year from 2007 to 2020. Error bars in (D), (E), (F), and (G) represent the SEM across $n = 14$ considered years (2007 to 2020). Significance levels are defined as follows: ns, $P \geq 0.05$; *$P < 0.05$; **$P < 0.01$; ***$P < 10^{-3}$.

inclusive leadership as a tool to increase employee satisfaction will, in the long term, help attract and retain talented young researchers, thus keeping academic organizations at the forefront of innovation. According to Katherine J. Kuchenbecker (director at the Max-Planck Institute for Intelligent Systems), "Hiring your first non-male lab members, breaking through that first diversity barrier can be hard, but it's worth it. [...] Then you become a magnet. Then almost all the women and diverse people accept your offers. They're all accepting my offers because they know that my lab is a safe space—and more than a safe space. It's a vibrant place. It's a place to thrive."

### Fairness and social justice

Ensuring diverse representation in robotics research not only helps correct historical imbalances and systemic inequities but also promotes fairness and equal opportunity for all (*26*–*28*)—regardless of their background and solely on the basis of their individual potential to advance robotic technologies for the benefit of humanity. According to Cosimo della Santina (associate professor at Delft University of Technology), having diversity and inclusive leadership in robotics is a priority; it "[...] comes first. It's a matter of justice, of being socially correct."

## CREATING AND FOSTERING DIVERSE AND INCLUSIVE TEAMS

Although it may seem that merely increasing the representation of historically marginalized groups in academic institutions would automatically lead to enhanced creativity and disruptive innovation, the full benefits (Fig. 1) of diversity can only be realized, and the potential challenges can only be mitigated (*29*), when those individuals feel safe and valued enough to express themselves and to actively participate in team projects and decision-making. Consequently, leaders are required to go beyond mere representation and to actively foster an inclusive culture. We outline specific points that leaders can address to reap the benefits of diversity and inclusion toward promoting scientific excellence in robotics.

### Revise hiring and practice targeted recruitment

All interviewed professors agreed that the most effective way to hire more diverse teams is to broaden recruitment pools. Inclusive leaders actively seek candidates from underrepresented groups, post job openings in diverse forums, and use inclusive language to encourage all qualified individuals to apply. Furthermore, Michelle Johnson (associate professor at University of Pennsylvania) recommended being "deliberate in recognizing potential" when hiring. She noted, "I'm looking for the best of the best, but I realized that a GPA of 4.0 doesn't always qualify that back to the best [candidate]. Oftentimes it has to do with character and having to build work

ethic in addition to that." Last, implementing blind review processes can help minimize unconscious biases during initial screening of talent pools.

### Foster a culture of inclusion

An inclusive environment is one where all team members feel valued, are involved in decision-making, and experience a sense of belonging and of psychological safety (*30*–*32*). Inclusive leaders strive to create safe spaces where all team members can express concerns about bias in technology and where they can share unconventional ideas (which could potentially lead to scientific breakthroughs). To this end, inclusive leaders facilitate constructive and empathic communication, take measures toward enhancing team cohesion, and encourage mutual support (for example, by encouraging collaborative projects within the lab). According to Monroe Kennedy III (assistant professor at Stanford University), "It helps to have a few very basic policies. We have policies to perform scientific excellence, but then beyond that, it's also about fostering an environment where curiosity and open mindedness is a norm. I was very fortunate with my very first PhD students, who were really amazing and helped set the tone for an amazing community in my lab that we've helped to grow around these ideals."

### Ensure wide accessibility to resources

It is important that facilities and resources are accessible to all individuals (including those with disabilities) and that lab knowledge is shared with everyone, for example, by using a common working language in international teams. To avoid that underrepresented team members feel marginalized, inclusive leaders facilitate access to support networks and communities. Another important measure is adopting flexible work policies that accommodate different cultural practices, personal needs, and family responsibilities (*33*). "The kind of contribution that should be made whenever there is an opportunity is offering childcare at conferences. In the end, it's a very simple thing: You offer a kindergarten in the same place where the conference is, and that's a real, concrete measure for enabling parents to travel to the conference," said Cecilia Laschi, professor at the National University of Singapore.

### Provide role models

Increase visibility of role models by inviting speakers from underrepresented backgrounds or by collaborating with them on projects. This approach helps underrepresented team members envision themselves as future academic thought leaders, an effect that also has been shown with respect to representation in conference leadership roles (*34*). Inclusive leaders themselves also aim to act as role models by challenging the status quo, raising awareness of systemic discrimination, and creating a safe environment for reporting discriminatory incidents.

### Strengthen mentorship and allyship

Scientific excellence is not only about putting cutting-edge knowledge into the world but also about training a new generation of emerging leaders, in particular team members from underrepresented backgrounds. This is where allyship and mentorship play a crucial role. Actively advocating for talented researchers and adapting mentorship styles according to individual team members' communication types, current needs, and career aspirations can be challenging, but it goes a long way. "[...] in addition to serving as a role model, I think [what is important] is also serving as an advocate and helping to create pathways for students that they didn't even know existed to begin with. I have definitely had some mentors in my life who have clearly shaped me. I would literally not be here today as a faculty member had it not been for certain individuals who created opportunities for me where I thought doors were sort of closed," shared Jeremy D. Brown.

### Facilitate promotion and advancement

Provide opportunities for all team members to develop skills and advance their careers, including access to conferences, leadership training, and participation in key projects. Establish transparent criteria for advancement (such as nominations for prizes, fellowships, and bonuses) and ensure that they are equitably applied to all team members. Further, actively advocate for team members who are on the job market by promoting them at conferences for roles that best align with their interests and career goals; this, in turn, also helps other lab leaders hire excellent researchers from a broad talent pool.

### Adapt research agendas and methods

Inclusive leaders embrace unusual ideas and interests of their team members and are open to provide the resources to redirect research agendas and methods accordingly. "I've benefited in my own lab from having people who have varied interests and varied backgrounds. Some of the problems that I solve don't necessarily come from my lived experience or even initially my interests but were spawned by interests of my students who brought in different backgrounds, different experiences, different interests. And that led to us doing very impactful work that I would not have otherwise done," declared Monroe Kennedy III. Furthermore, ensuring diverse representation among user study participants is imperative to create broadly beneficial human-centric technologies.

To conclude, in the first section of this viewpoint article, we highlight a variety of benefits of embracing diversity and inclusive leadership for scientific excellence in robotics research. The citation analysis presented here identified a positive correlation between gender diversity and citation rates in robotics; these results motivate future research to investigate correlations between research performance and additional dimensions of diversity, as well as to use analysis techniques that allow inference of causality. In the second section, we provide a guideline for leaders to reap the benefits of diverse and inclusive teams. Implementing the outlined principles requires consistent effort and commitment from all levels of the team—especially leadership. We acknowledge that there exist cultural and geographic differences and that creating, nurturing, and leading a diverse and inclusive lab can be challenging. However, just like Josie Hughes (assistant professor at EPFL) highlighted, "Having diversity in thought means you [as a leader] have to perhaps understand people's way of thinking or people's background a little bit more, but that allows you to grow as an individual. [...] You've got to be willing to accept the fact that you need to grow, you need to learn, which has some overhead, some costs, but has a larger long-term overall benefit in terms of productivity and innovation."

## Supplementary Materials

**This PDF file includes:**

Materials and Methods
Table S1
Figs. S1 to S8
References (*35*–*38*)

## REFERENCES AND NOTES

1. B. K. AlShebli, T. Rahwan, W. L. Woon, The preeminence of ethnic diversity in scientific collaboration. *Nat. Commun.* **9**, 5163 (2018).
2. M. R. Hebl, D. R. Avery, "Diversity in organizations" in *Industrial and Organizational Psychology*, I. B. Weiner, Ed., vol. 12 of *Handbook of Psychology* (Wiley, 2012), pp. 677–697.

3. V. Hunt, S. Dixon-Fyle, C. Huber, M. del Mar Martinez Márquez, S. Prince, A. Thomas, *Diversity Matters Even More: The Case for Holistic Impact* (McKinsey & Company, 2023).
4. L. G. Campbell, S. Mehtani, M. E. Dozier, J. Rinehart, Gender-heterogeneous working groups produce higher quality science. *PLOS ONE* **8**, e79147 (2013).
5. R. B. Freeman, W. Huang, Collaborating with people like me: Ethnic coauthorship within the United States. *J. Labor Econ.* **33**, S289–S318 (2015).
6. S. E. Page, *The Diversity Bonus: How Great Teams Pay Off in the Knowledge Economy* (Princeton Univ. Press, 2017).
7. L. Hong, S. E. Page, Groups of diverse problem solvers can outperform groups of high-ability problem solvers. *Proc. Natl. Acad. Sci. U.S.A.* **101**, 16385–16389 (2004).
8. A. W. Woolley, C. F. Chabris, A. Pentland, N. Hashmi, T. W. Malone, Evidence for a collective intelligence factor in the performance of human groups. *Science* **330**, 686–688 (2010).
9. B. Hofstra, V. V. Kulkarni, S. Munoz-Najar Galvez, B. He, D. Jurafsky, D. A. McFarland, The diversity–innovation paradox in science. *Proc. Natl. Acad. Sci. U.S.A.* **117**, 9284–9291 (2020).
10. S. Jang, Cultural brokerage and creative performance in multicultural teams. *Organ. Sci.* **28**, 993–1009 (2017).
11. C. Díaz-García, A. González-Moreno, F. J. Sáez-Martínez, Gender diversity within R&D teams: Its impact on radicalness of innovation. *Innovation* **15**, 149–160 (2013).
12. M. W. Nielsen, S. Alegria, L. Börjeson, H. Etzkowitz, H. J. Falk-Krzesinski, A. Joshi, E. Leahey, L. Smith-Doerr, A. W. Woolley, L. Schiebinger, Gender diversity leads to better science. *Proc. Natl. Acad. Sci. U.S.A.* **114**, 1740–1742 (2017).
13. M. de Vaan, D. Stark, B. Vedres, Game changer: The topology of creativity. *Am. J. Sociol.* **120**, 1144–1194 (2015).
14. B. Vedres, O. Vásárhelyi, Inclusion unlocks the creative potential of gender diversity in teams. *Sci. Rep.* **13**, 13757 (2023).
15. R. Koning, S. Samila, J.-P. Ferguson, Who do we invent for? Patents by women focus more on women's health, but few women get to invent. *Science* **372**, 1345–1348 (2021).
16. A. Matsiko, B. J. Nelson, Robotics and AI in the global south. *Sci. Robot.* **8**, eadm9727 (2023).
17. R. B. Freeman, W. Huang, Collaboration: Strength in diversity. *Nature* **513**, 305 (2014).
18. Z. Obermeyer, B. Powers, C. Vogeli, S. Mullainathan, Dissecting racial bias in an algorithm used to manage the health of populations. *Science* **366**, 447–453 (2019).
19. B. F. Klare, M. J. Burge, J. C. Klontz, R. W. V. Bruegge, A. K. Jain, Face recognition performance: Role of demographic information. *IEEE Trans. Inf. Forensics Secur.* **7**, 1789–1801 (2012).
20. J. L. J. Angwin, S. Mattu, L. Kirchner, "Machine bias," *ProPublica* (23 May 2016); https://propublica.org/article/machine-bias-risk-assessments-in-criminal-sentencing.
21. R. Schwartz, A. Vassilev, K. Greene, L. Perine, A. Burt, P. Hall, "Towards a standard for identifying and managing bias in artificial intelligence" (National Institute of Standards and Technology Special Publication 1270, US Department of Commerce, 2022); https://doi.org/10.6028/NIST.SP.1270.
22. B. Cowgill, F. Dell'Acqua, S. Deng, D. Hsu, N. Verma, A. Chaintreau, Biased programmers? Or biased data? A field experiment in operationalizing AI ethics, in *Proceedings of the 21st ACM Conference on Economics and Computation* (ACM, 2020), pp. 679–681.
23. A. Howard, M. Kennedy III, Robots are not immune to bias and injustice. *Sci. Robot.* **5**, eabf1364 (2020).
24. D. R. Avery, S. D. Volpone, R. W. Stewart, A. Luksyte, M. Hernandez, P. F. McKay, M. R. Hebl, Examining the draw of diversity: How diversity climate perceptions affect job-pursuit intentions. *Hum. Resour. Manage.* **52**, 175–193 (2013).
25. A.-L. Claeys-Kulik, T. E. Jørgensen, H. Stöber, "Diversity, equity and inclusion in European higher education institutions: Results from the INVITED project" (European University Association, 2019).
26. C. A. Urbina-Blanco, S. Z. Jilani, I. R. Speight, M. J. Bojdys, T. Friščić, J. F. Stoddart, T. L. Nelson, J. Mack, R. A. S. Robinson, E. A. Waddell, J. L. Lutkenhaus, M. Godfrey, M. I. Abboud, S. O. Aderinto, D. Aderohunmu, L. Bibič, J. Borges, V. M. Dong, L. Ferrins, F. M. Fung, T. John, F. P. L. Lim, S. L. Masters, D. Mambwe, P. Thordarson, M.-M. Titirici, G. D. Tormet-González, M. M. Unterlass, A. Wadle, V. W.-W. Yam, Y.-W. Yang, A diverse view of science to catalyse change. *Nat. Chem.* **12**, 773–776 (2020).
27. National Center for Science and Engineering Statistics, "Diversity and STEM: Women, minorities, and persons with disabilities" (Special Report NSF 23-315, National Science Foundation, 2023).
28. E. A. Cech, T. J. Waidzunas, Systemic inequalities for LGBTQ professionals in STEM. *Sci. Adv.* **7**, eabe0933 (2021).
29. D. Van Knippenberg, L. H. Nishii, D. J. G. Dwertmann, Synergy from diversity: Managing team diversity to enhance performance. *Behav. Sci. Policy* **6**, 75–92 (2020).
30. Y. R. F. Guillaume, J. F. Dawson, L. Otaye-Ebede, S. A. Woods, M. A. West, Harnessing demographic differences in organizations: What moderates the effects of workplace diversity? *J. Organ. Behav.* **38**, 276–303 (2017).
31. L. H. Nishii, The benefits of climate for inclusion for gender-diverse groups. *Acad. Manag. J.* **56**, 1754–1774 (2013).
32. C. Puritty, L. R. Strickland, E. Alia, B. Blonder, E. Klein, M. T. Kohl, E. McGee, M. Quintana, R. E. Ridley, B. Tellman, L. R. Gerber, Without inclusion, diversity initiatives may not be enough. *Science* **357**, 1101–1102 (2017).
33. S. Aracri, J. Hughes, C. D. Santina, J. Jovanova, S. Hoh, D. S. G. Morales, R. Barcaro, Y. J. Tan, V. G. Kortman, A. Sakes, A. J. Partridge, M. Cianchetti, C. Laschi, B. Mazzolai, A. A. Stokes, P. V. Alvarado, C. H. Yeow, A. Odetti, V. Lo Gatto, L. Pisacane, M. Caccia, Soft robotics: A route to equality, diversity, and inclusivity in robotics. *Soft Robot.* 10.1089/soro.2023.0225 (2024).
34. L. Graesser, A. Faust, H. Kress-Gazit, L. Tapia, R. Ulinski, Gender diversity of conference leadership [Women in Engineering]. *IEEE Robot. Autom. Mag.* **28**, 126–130 (2021).
35. Web of Science Core Collection; https://webofscience.com/wos/woscc/basic-search.
36. Genderize.io; https://genderize.io/.
37. K. Wais, Gender prediction methods based on first names with genderizeR. *R J.* **8**, 17–37 (2016).
38. Condens.io; https://condens.io/.


**Acknowledgments:** We thank J. D. Brown, M. de Graaf, J. Hughes, M. Johnson, M. Kennedy III, K. J. Kuchenbecker, C. Laschi, B. Mazzolai, A. Okamura, and C. della Santina for participating in the interviews; in particular, we would like to thank K. J. Kuchenbecker for inspiring leadership in promoting diversity and inclusion at the Max-Planck Institute for Intelligent Systems; we thank N. Ducal for help in collecting the publication data and S. Kirkman and E. Rumley for helpful suggestions on the manuscript. **Funding:** D.M., K.K., and C.K. acknowledge funding from the Max Planck Society, Germany. D.M. acknowledges funding from the Max Planck ETH Center for Learning Systems. A.F. acknowledges funding from the EMBO postdoctoral fellowship ALTF 688-2022. **Author contributions:** Conceptualization: D.M., K.K., and C.K. Methodology: D.M., K.K., and C.K. Investigation: D.M. and A.F. Visualization: D.M. and A.F. Funding acquisition: K.K. and C.K. Project administration: D.M. Supervision: K.K. and C.K. Writing—original draft: D.M. Writing—review and editing: D.M., A.F., K.K., and C.K. **Competing interests:** The authors declare that they have no competing interests. **Data and materials availability:** All data and code used in the analysis of this work can be found in the following repository: https://doi.org/10.17617/3.BC0G6F.

10.1126/scirobotics.adt1958