Title: Shifting institutional culture to develop climate solutions with Open Science

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> “To address our climate emergency, we must rapidly, radically reshape society. We need every solution and every solver”. - Ayana Elizabeth Johnson & Katharine Wilkinson, *All We Can Save*

This call to action by Drs. Johnson and Wilkinson is part of a mosaic of voices sharing tangible progress within the climate movement [1,2]. This call speaks to us as environmental and Earth scientists motivated by the urgency of climate change and social inequity and who contribute to finding science-driven climate solutions as part of our daily jobs. Unfortunately, we are often unable to efficiently move this critical and urgent work forward because we are impeded by cumbersome daily workflows and restrictive workplace cultures. Our workplaces have not kept pace with the modern realities of data-intensive science: increasing data volumes and storage needs, rapidly-evolving technology, new skill requirements, and a growing need for extensive and diverse collaboration. Struggling with old approaches and learning new ones in isolation can fuel burnout and turnover, preventing us from working on science-driven climate solutions effectively.

We are making progress forward through Open Science, a movement that has grown through decades of grassroots efforts and over many organizational levels [3]. Open Science is “the principle and practice of making research products and processes available to all, while respecting diverse cultures, maintaining security and privacy, and fostering collaborations, reproducibility, and equity” (https://open.science.gov), and the U.S. White House Office of

Science and Technology Policy (OSTP) declared 2023 as a Year of Open Science with an action to “accelerate discovery and innovation”[4]. We are experiencing indispensable scientific benefits and positive culture shifts in our research workplaces by using Open Science to elevate our colleagues, build collaboration, and ultimately address climate change impacts.

Here, we share our best advice for connecting climate solutions and Open Science through our daily work. “Climate" need not be in our job titles or project descriptions for us to identify as part of climate solutions: all of our work must consider a changing climate. We work with people and ecosystems impacted by climate change, including managing fish species that are migrating due to changing ocean temperatures, and freshwater ecosystems impacted by fluctuating drought, flooding, and pollutants. We have found vast improvements to the quality and impact of our work and our teams’ morale through a culture change that helps us identify as part of the Open Science and climate movements. Culture change will not happen without learning the unfamiliar and unlearning the familiar; yet, this process does not need to be an upheaval or started from scratch. It starts with holding intentional, respectful conversations and tapping into the knowledge base of our workplaces, and reusing what works in new places. Climate change solutions will require novel, multifaceted solutions that employ many nuanced skills and perspectives, which are best nurtured through trust and deliberate sharing of knowledge. We emphasize the need to prioritize peer learning as part of our jobs.

Rapidly, radically reshaping climate change science means investing in both technical and social infrastructure

Bringing the urgency of “Rapidly, radically reshaping society” [1] to climate-driven Open Science requires investment not only in technical infrastructure – such as programmatic open source code (e.g., R, Python, Julia), platforms (e.g., GitHub, cloud computing), and literate programming (e.g., Jupyter Notebooks, Quarto) – but also synergistically in social infrastructure to learn these technologies and continue learning as technologies evolve (Figure 1). This is particularly true for diverse teams involved in climate change science, many of whom have not been formally trained in computing. While most organizations already value the effects of “power skills”[6] such as effective oral and written communication, action-oriented agendas, group facilitation, and focused listening, few have truly invested in building a supportive social infrastructure. Such social infrastructure relies on creating a culture that supports psychological safety, where we feel safe to speak up with diverse perspectives, [7] and growth mindsets, where we believe they have the capacity to learn [5]. This social infrastructure underpins healthy collaborations [8] and is made possible through shared values of emotional intelligence, empathy, compassion, trust, holding space for and navigating difficult conversations, effective confrontation, and giving and receiving constructive feedback. These are skills we can learn. Investing in social infrastructure and explicitly acknowledging, valuing, and rewarding this otherwise invisible work helps collaborators feel comfortable to share innovative ideas, develop new skills, ask questions, and learn from feedback, and benefits the collective organizational culture.

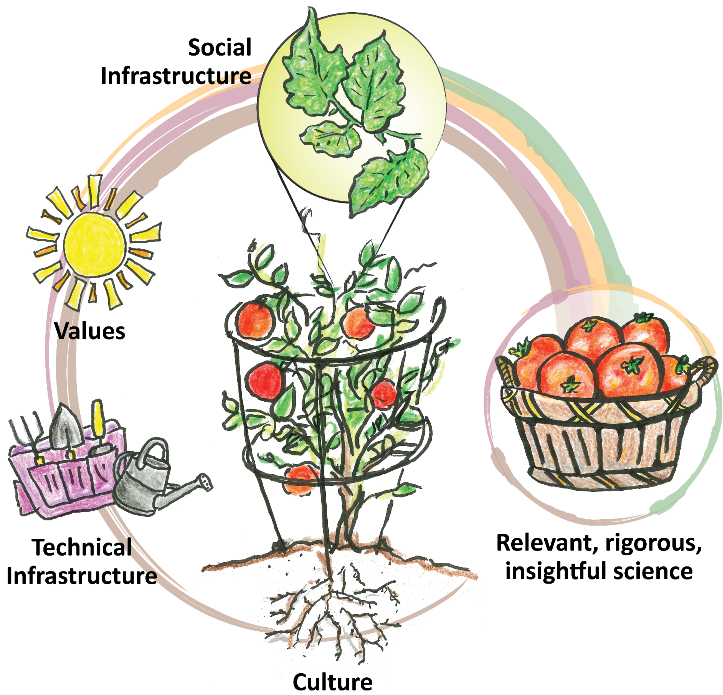

Figure 1: Similar to how plants use the resources available to them to develop healthy flowers and fruits, values, culture, and technical infrastructure are organizational resources maximized by social infrastructure to create relevant, rigorous, and insightful science. Illustration by Adyan Rios and Su Kim, NOAA Fisheries.

Developing social infrastructure within an organization requires support from leadership and grassroots efforts [9]. Supervisors can foster supportive social infrastructure by creating and enforcing codes of conduct, encouraging open sharing and collaboration through explicit policies, and valuing community organization and reproducible products as highly as publications [14,15]. Through investing in real relationships and collaboration, we can build morale through learning [10] , with individuals and teams reevaluating their objectives and workflows in light of new tools, resources, and user needs. The challenge of making substantial changes to workflows built over entire careers can be exciting for early adopters and an unsettling prospect for many others [11], often exacerbated by the shame,vulnerability, and time involved around learning and implementing new technology [12,13]. Further, it can mean substantial changes to collaborating with others, challenging siloed-work assumptions of “I work alone”, and “that person won’t learn technical (or social) skills”, as well as what expertise has value, who they can learn from, and who they can become.

Building agency in individuals and movements across institutions

“Rapidly, radically reshaping” culture is about us all having agency to take advantage of the opportunities that new technology provides. Change on a massive scale appears daunting, but social infrastructure is built from many small opportunities and is actionable through small daily habits that, together, transform how we work [16] [17].

We offer a case study and concrete advice for building skills and confidence in ourselves and across our institutions. We have collaborated through Openscapes, an approach supporting teams with technical and social infrastructure and Open Science[18]. We have seen and learned three main lessons by working with our teams but connected across a bigger Open Science community. 1) We have more time to spend on science and solutions. Beyond time saved, we create better products like data-driven reports and documentation for our research and management partners that incur less loss during day-to-day maintenance, and during succession. 2) We have improved team morale, which helps us more effectively maneuver around technical hurdles, more candidly ask for help, and form truly collaborative relationships across institutions. 3) By connecting our biggest challenges around climate and social change with our daily work, we feel renewed purpose and motivation to contribute with collective agency, voice, and action.

The impact from this technical and cultural change shows up in many ways. NOAA Fisheries hosts regularly scheduled learning meetups, which has helped teams from across the country reuse rather than reinvent similar code and onboard during the pandemic, which was otherwise quite isolating. Co-author A. Rios estimated that “using GitHub saved me 400 would-be emails in 4 months” because project statuses and files were easy to find and keep up to date. The US EPA Office of Research and Development and NOAA Fisheries have nascent open science communities of practice with a goal of improving skills, sharing knowledge, and supporting adoption of open science practices. Through collaborating together to support researchers using NASA Earthdata on the Cloud, the NASA Distributed Active Archive Centers (DAAC)s created both conceptual cheatsheets and the earthaccess python library to help reduce the ‘time to science’ [19] . The California Water Boards are experimenting with iterating, customizing, and scaling structured learning throughout the organization. Co-author I. Fenwick identified a major under-representation of Black researchers in her community being included in the Open Science community, and she designed a program grounded in trust and built in partnership with Black marine science faculty and community leads. The event series kicked off with 80 participants and a focus on “What is Open Science anyways?” and built relationships over time while coworking and screensharing on specific problems participants brought to discuss. Over time, these impacts are also being shared and promoted in peer-reviewed research publications that describe R packages and workflows that other groups can reuse in their own fisheries science (e.g., Bastille et al 2021).

Our best advice: regularly scheduled collaborative learning meetings

Our best advice is to have regularly scheduled learning meetings with structure and intention to make them different from other work meetings. We suggest naming them to give them identity and value, such as “coworking” or “Seaside Chats”. In coworking meetings, people convene in pairs or a group to seek, offer, and accept guidance from one another as they screenshare and walk through a workflow, discuss a data challenge, write documentation, or learn a new tool [24]. Coworking sessions can also be shaped around a goal or deliverable like developing tutorials for the NASA Earthdata Cloud Cookbook. Following coworking, co-author A. Barrett said: "I had an epiphany as to what real-time collaborative work could be. I think it comes down to the mutual trust and respect within [coworking] that allows me to not be afraid to make mistakes or not know what I am doing, even with an audience."

Coworking is where we learn new skills of immediate value for our daily research, from efficient keyboard shortcuts (like shift-option-arrow to highlight text on a Mac) to paired programming, an established coworking practice in software development [25]. It's also where we learn facilitation skills like how to design inclusive and purposeful meeting agendas that can adapt to evolving needs in real time. Coworking is where someone leans forward in their chair while a colleague is screen-sharing and says "I need that, can you teach me?" and draws from the Open Science community so that what we learn extends beyond what the team already knows. In coworking, it is critical that people opt-in to being present, learning, and sharing. This helps set expectations for mutual trust and is a key element of movement building that supports the willing first [1,26] .

To get started, reach out to a colleague or group and plan a time to meet. You do not have to be an expert on a given topic and there are topics to get you started [24,27–29]. Schedule a recurring slot in your calendars to help the group prioritize peer-learning time; try weekly 1-hour or bi-weekly 1.5 hour sessions. Create a single collaborative document (e.g., google docs) for a year's worth of coworking sessions. This document gives all coworking members one place to write notes, share links, and paste screenshots that is searchable and accessible, and is a known resource if folks lose internet or otherwise cannot attend[30].

Tell colleagues and supervisors about your coworking sessions so they can amplify and/or join. Having leaders and supervisors coworking alongside team members, and enforcing codes of conduct, can create momentum and help new practices stick across daily tasks and work environments [24]. We see the trust and expectations established in synchronous coworking carry over into asynchronous communication spaces like Slack, gchat, or Microsoft Teams and in in-person and hybrid interactions. Making this practice visible is part of rapid and radical reshaping: it improves morale and gives permission to other teams and organizations to adopt it as well.

Shifting institutional culture to develop climate solutions with Open Science

Through "radically, rapidly reshaping" climate change science, we are seeing culture shifts within our institutions from one that values individual contribution to one that fosters meaningful collaboration – the clearest path to the innovations necessary to mitigate the impending climate change-related shocks. This work is hard and messy, and progress is not linear – and it is only possible if all participants feel comfortable asking questions about what they do not understand and are received with patience and interest [31]. It is not about ephemeral alliances to avoid conflict, it is about long-term collaboration (e.g., giving and receiving feedback, reflection and growth mindset) where growth mindsets can flourish and individuals have the toolsets to face new and/or hard problems.

Support and enthusiasm from leadership to connect developing new skills with technology-enabled culture change is critical. This is a big time investment, and we need every solution and every solver [1]. Finding solutions to climate change necessitates bringing together diverse talent, sharing knowledge, using the latest technological advances, and having effective teams.This means that, no matter the role you play, you have a place in the Open Science movement: please join us.

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Disclaimers

The views expressed in this article are those of the authors and do not necessarily represent those of the California State Water Resources Control Board.

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purposes. DOE will provide public access to these results of federally sponsored research in accordance with the DOE Public Access Plan (https://www.energy.gov/doe-public-access-plan).

References

1. Johnson, A. E. & Wilkinson, K. K. *All We Can Save: Truth, Courage, and Solutions for the Climate Crisis*. (One World, 2020).
2. Urai, A. E. & Kelly, C. Rethinking academia in a time of climate crisis. *eLife* **12**, e84991 (2023).
3. Budapest Open Access Initiative. Budapest Open Access Initiative. (2001).
4. The White House. FACT SHEET: Biden-Harris Administration Announces New Actions to Advance Open and Equitable Research | OSTP. (2023).
5. O'Keefe, P. A., Dweck, C. S. & Walton, G. M. Implicit Theories of Interest: Finding Your Passion or Developing It? *Psychol. Sci.* **29**, 1653–1664 (2018).
6. Michail, J. Council Post: Elevate Your Soft Leadership Skills: The Real Power Skills. *Forbes* https://www.forbes.com/sites/forbescoachescouncil/2022/12/29/elevate-your-soft-leadership-skills-the-real-power-skills/.
7. Edmondson, A. Psychological Safety and Learning Behavior in Work Teams. *Adm. Sci. Q.* **44**, 350–383 (1999).
8. Cheruvelil, K. S. & Soranno, P. A. Data-Intensive Ecological Research Is Catalyzed by Open Science and Team Science. *BioScience* **68**, 813–822 (2018).
9. Friesz, A. *et al.* 3 takeaways for planning for the year of open science. *3 takeaways for planning for the year of open science* https://www.openscapes.org/blog/2022/02/17/esip-winter-2022// (2022).
10. 3 approaches for the year of open science. https://www.openscapes.org/blog/2023/03/16/esip-winter-2023//.
11. Rogers, E. *Diffusion of Innovations*. (Free Press, 2003).

12. Brené with Paul Leonardi and Tsedal Neeley on The Digital Mindset, Part 1 of 2. *Brené Brown* https://brenebrown.com/podcast/the-digital-mindset-part-1-of-2/.

13. The Digital Mindset: What It Really Takes to Thrive in the Age of Data, Algorithms, and AI. *Tsedal Neeley* https://www.tsedal.com/book/the-digital-mindset/.

14. Gentemann, C. *et al.* NASA Open-Source Science Initiative: Transform to OPen Science (TOPS). (2021) doi:10.5281/zenodo.5621674.

15. National Academies of Sciences, Engineering, and Medicine. *Developing a Toolkit for Fostering Open Science Practices: Proceedings of a Workshop*. (The National Academies Press, 2021). doi:10.17226/26308.

16. Atomic Habits: An Easy & Proven Way to Build Good Habits & Break Bad Ones. *James Clear* https://jamesclear.com/atomic-habits.

17. Benjamin, R. *Viral Justice*.

18. Robinson, E. & Lowndes, J. S. S. The Openscapes Flywheel: A framework for managers to facilitate and scale inclusive Open science practices. (2022) doi:https://doi.org/10.31223/X5CQ02.

19. NASA Openscapes Mentors. EarthData Cloud Cookbook - NASA Earthdata Cloud Cookbook. (2022).

20. Barone, L., Williams, J. & Micklos, D. Unmet Needs for Analyzing Biological Big Data: A Survey of 704 NSF Principal Investigators. *bioRxiv* 108555 (2017) doi:10.1101/108555.

21. Williams, J. J. *et al.* Barriers to integration of bioinformatics into undergraduate life sciences education: A national study of US life sciences faculty uncover significant barriers to integrating bioinformatics into undergraduate instruction. *PLOS ONE* **14**, e0224288 (2019).

22. Williams, J. J., Tractenberg, R. E., Batut, B. & Becker, E. Optimizing Short-format Training: an International Consensus on Effective, Inclusive, and Career-spanning Professional Development in the Life Sciences and Beyond | bioRxiv. *BioRxiv Prepr.* (2023) doi:https://doi.org/10.1101/2023.03.10.531570.

23. Braga, P. H. P. *et al.* Not just for programmers: How GitHub can accelerate collaborative and reproducible research in ecology and evolution. *Methods Ecol. Evol.* **14**, 1364–1380 (2023).

24. Lowndes, J. S. S. *et al.* Supercharge your research: a ten-week plan for open data science. *Nature* (2019) doi:10.1038/d41586-019-03335-4.

25. On Pair Programming. *martinfowler.com* https://martinfowler.com/articles/on-pair-programming.html.

26. Moore, G. A. *Crossing the Chasm, 3rd Edition: Marketing and Selling Disruptive Products to Mainstream Customers*. (Harper Business, 2014).

27. Gaynor, K. M. *et al.* Ten simple rules to cultivate belonging in collaborative data science research teams. *PLOS Comput. Biol.* **18**, e1010567 (2022).

28. Goodman, A. *et al.* Ten Simple Rules for the Care and Feeding of Scientific Data. *PLOS Comput. Biol.* **10**, e1003542 (2014).

29. Perez-Riverol, Y. *et al.* Ten Simple Rules for Taking Advantage of Git and GitHub. *PLOS Comput Biol* **12**, e1004947 (2016).

30. Lowndes, J. S. S., Cabunoc Mayes, A. & Sansing, C. 3 lessons from remote meetings we’re taking back to the office | Opensource.com. *OpenSource.com* (2020).

31. Lowndes, J. S. Open Software Means Kinder Science. *Sci. Am. Blog Netw.* (2019).

32. Bryan, J. & Hester, J. *What They Forgot to Teach You About R*. (2022).