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Opening Up to Open Science

More inclusive open science can help solve society's most pressing problems—and at a faster pace—but making it mainstream requires systemic institutional change.

The modern Hippocratic Oath outlines ethical standards that physicians worldwide swear to uphold. “I will respect the hard-won scientific gains of those physicians in whose steps I walk,” one of its tenets reads, “and gladly share such knowledge as is mine with those who are to follow.”

But what form, exactly, should knowledge-sharing take? In the practice of modern science, knowledge in most scientific disciplines is generally shared through peer-reviewed publications at the end of a project. Although publication is both expected and incentivized—it plays a key role in career advancement, for example—many scientists do not take the extra step of sharing data, detailed methods, or code, making it more difficult for others to replicate, verify, and build on their results. Even beyond that, professional science today is full of personal and institutional incentives to hold information closely to retain a competitive advantage.

This way of sharing science has some benefits: peer review, for example, helps to ensure (even if it never guarantees) scientific integrity and prevent inadvertent misuse of data or code. But the status quo also comes with clear costs: it creates barriers (in the form of publication paywalls), slows the pace of innovation, and limits the impact of research. Fast science is increasingly necessary, and with good reason. Technology has not only improved the speed at which science is carried out, but many of the problems scientists study, from climate change to COVID-19, demand urgency. Whether modeling the behavior of wildfires or developing a vaccine, the need for scientists to work together and share knowledge has never been greater. In this environment, the rapid dissemination of knowledge is critical; closed, siloed knowledge slows progress to a degree society cannot afford. Imagine the consequences today if, as in the 2003 SARS disease outbreak, the task of sequencing genomes still took months and tools for labs to

share the results openly online didn't exist. Today's challenges require scientists to adapt and better recognize, facilitate, and reward collaboration.

Open science is a path toward a collaborative culture that, enabled by a range of technologies, empowers the open sharing of data, information, and knowledge within the scientific community and the wider public to accelerate scientific research and understanding. Yet despite its benefits, open science has not been widely embraced. One approach to advance open science adoption has been to ask scientists to take an oath or pledge that includes open science as a tenet; several of these pledges have been proposed (in 1999, 2013, 2017, and 2018), but none have been broadly put in practice. We believe this is because the commitment was focused on individual scientists rather than the framework and communities they work within. Open science pledges can only work where organizations are already fully committed and supportive. Even if an individual researcher wants to openly share knowledge, institutional policies and reward systems create barriers.

Although some institutions recognize the opportunity that open science provides for attracting a more diverse workforce and increasing collaborative networks and innovation, others continue to equate the sharing of knowledge with relinquishing a competitive advantage. This manifests in a range of institutional policies and workforce incentives. Some institutions are limited by what publication expenses they can cover for making articles open access, while those with large computer clusters may prevent their researchers from working in more open, collaborative, cloud-based platforms. Outdated institutional intellectual property policies often conflict directly with open-source software contributions and software development, and awards commonly recognize

individuals rather than teams. From small annoyances to larger career impacts, institutional policies create friction that inhibits participation in open science.

This tension between individual and institutional incentives and the progress of science must be recognized and resolved in a manner that contributes to solving the great challenges of today and the future. To change the culture, researchers must do more than take a pledge; they must change the game—the structures, the policies, and the criteria for success. In a word, open science must be *institutionalized*.

Open science is better science

A powerful open science story can be found in the World Climate Research Programme's Coupled Model Intercomparison Project (CMIP), established in 1995. Before CMIP, with the internet in its infancy, climate model results were scattered around the world and difficult to access and use. CMIP inspired 40 modeling groups and about 1,000 researchers to collaborate on advancing modeling techniques and setting guidelines for how and where to share results openly. That simple step led to an unexpected transformation: as more people were able to access the data, the community expanded, and more groups contributed data to CMIP. More people asking questions and pointing out issues in their results helped drive improvements. In its assessment reports, the Intergovernmental Panel on Climate Change relied on research publications using CMIP data to assess climate change. As a platform, CMIP enabled thousands of scientists to work together, self-correct their work, and create further ways to collaborate—a virtuous circle that attracted more scientists and more data, and increased the speed and usefulness of the work.

While the increased volume of data was a sign of success, over time the community began to struggle to provide access to all its data. The Pangeo open science community stepped in to help. Established in 2016 when a group of scientists began trying to address barriers to big-data oceanography, Pangeo was designed as an inclusive, open community of scientists and software developers to create an ecosystem where anyone could raise an idea or issue, with community members organically teaming up to contribute their unique skills. Pangeo scientists and software developers worked together to create a cloud-optimized version of the 800-terabyte dataset as well as open-source tools to help with analyses. Today, instead of spending three to six months downloading the CMIP data to a local computer and years developing analyses, model data are freely available on the cloud, and anyone can examine them in just a few minutes.

Open science communities such as these exist in many different areas of science, and they are helping science move faster and work better. But the type of knowledge-sharing and collaboration exemplified by CMIP and Pangeo must become standard, which requires institutionalizing these practices.

Taking open science mainstream

Even as individual scientists and groups decide to be more open, they could still face institutional roadblocks. Organizations must therefore incentivize researchers to build inclusive, diverse research groups that facilitate true interdisciplinary work, remove roadblocks to collaboration, and foster an environment where knowledge is shared and scientists are trained with open science as a core principle.

Some communities are already working toward these goals, including the Fort Lauderdale Agreement in biomedicine and the Berlin Declaration on Open Access to Knowledge. There has also been a flurry of recent recommendations on how to advance open science from the National Academies—which has developed a toolkit, software, and a vision for institutional design—and from UNESCO. These reports lay out clear guidelines for institutions, universities, funding agencies, and scientists to improve how science is done and expand who can participate (e.g., through open-access publications).

The most important message from these reports is that all parts of science, from individual researchers to universities and funding agencies, need to coordinate their efforts to ensure that early adopters aren't jeopardizing their careers by joining the open science community. The whole enterprise has to change to truly realize the full benefits of open science. Creating this level of institutional adoption also requires updating policies, providing training, and recognizing and rewarding collaborative science.

Update policies to support open science. Agencies and universities must update their software and data release policies so that scientists can work together quickly, effectively, and without fear. Institutions are too often mired in slow, cumbersome approval procedures that are incompatible with open software and collaborative science practices. For instance, while working at a NASA center, scientist Jane Rigby wanted to release a simple software tool to the public, a process, she laments, that “took five months and 38 pages of paperwork—to release 217 lines of nonsensitive code.”

Although careful approval is necessary at some institutions and in some fields where sensitive material is handled, these roadblocks should be restricted to projects that deal with that specific information. A tiered or more nuanced approach to risk is needed. For basic science, openness should be the default, especially as agencies and universities work to update disclosure requirements to account for national security risks.

Updating such policies to speed software and data releases will expand contributions to open-source software libraries; increase sharing of code so that results are more easily replicated and extended; and open new pathways to collaborations. The American Geophysical Union is working with its communities to move the norms and culture

toward sharing data and code as the default. As societies and publishers move toward more open science requirements, they are nudging institutions to adjust their policies. Once these policies have been changed, they need to be clearly and loudly communicated within organizations—otherwise the effects of the previous policies will linger, making scientists fear the paperwork of participating in open science.

Provide training in open science. Although data science programs are increasingly being added to university programs and curricula, computational training should occur in tandem with training in best practices for open science. Understanding how to work in an open science framework is a skill that scientists and project managers need to acquire.

A global effort to facilitate scientists' move to more open practices requires investments in learning resources that teach how to practice open science, build and participate in inclusive teams, and acquire basic data science skills and knowledge. Grassroots efforts—Google Groups, posts on Medium, Jupyter notebooks—have been filling this gap but could be built on, updated, and extended by teams with representation from all

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stakeholders and communities. Such resources should be freely and openly available online to be available to teachers and working groups.

Training in open science should begin at the undergraduate level and be offered to scientists and managers throughout all career stages. At every level, researchers should understand how to do open science, and funding agencies should support these efforts and tailor them to their communities. Asking scientists to change involves work, but such work can be incentivized through curated tutorials with badges or credits, and participation in open science should be rewarded by funding decisions.

Recognize and reward collaborative open science. We believe the hero scientist is a myth and that all science requires teamwork, even as the current incentive structure continues to reward individual achievements almost exclusively. This has remained the case despite the achievements of team science, as described, for example, in a 2015 report from the National Research Council: “Team science has led to scientific breakthroughs that would not otherwise have been possible, such as the discovery of the transistor effect, the development of antiretroviral medications to control AIDS, and confirmation of the existence of dark matter.”

To truly recognize and value teamwork, the scientific

reward system needs to be reconfigured from the ground up. Individual researchers must not suffer career consequences for openly sharing data, and funding agencies, hiring managers, institutions, and researchers need to consider everyone on a team as an actor. Only by moving toward a more inclusive, team-oriented model will science develop voices with different perspectives to challenge established beliefs and develop creative new answers.

Funding agencies should also review proposals with an eye toward their ultimate community benefits and open science activities. University performance evaluations, for their part, need to integrate documentation of community-building efforts and open science activities—including in hiring and tenure review—and assess how their policies should be revised. Professional society awards and fellowships could include open science in evaluations, and awards could recognize teams rather than individuals.

Sustaining momentum for change

In September 2021, the National Academies Roundtable on Aligning Incentives for Open Science released toolkit elements designed to help organizations ensure that their incentive systems encourage open science. In October 2021, NASA announced a new \$40 million, five-year mission, Transform to Open Science (TOPS), and declared 2023 as the Year of Open Science. TOPS' Year of Open Science jumpstarts a suite of coordinated activities designed to increase the understanding and adoption of open science principles and techniques, accelerate major scientific discoveries, and broaden participation by historically excluded communities in science. In November 2021, the UNESCO Recommendation on Open Science was formally adopted by 193 member countries and includes priority areas of actions to advance open science.

This momentum must be sustained. Now that major organizations have provided valuable road maps, institutions, agencies, and research centers must be convinced to follow them. Action at the individual and team level can only go so far toward solving what is truly a systemic shortcoming. It is only through changing institutional frameworks that open knowledge, data, software, and resources can become the rule rather than the exception. Moving to open, inclusive, community-driven science is a powerful way to rebuild trust with the public while also accelerating scientific discovery.

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