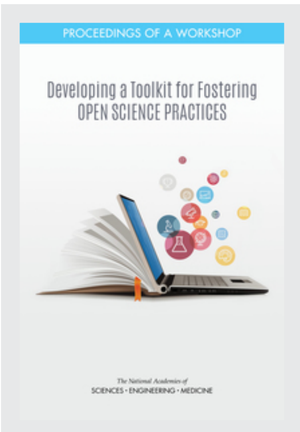

Developing a Toolkit for Fostering Open Science Practices: Proceedings of a Workshop (2021)

DETAILS

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Appendix C

Toolkit Elements

This appendix includes examples of draft elements of a toolkit that have been developed by members of working groups of the National Academies of Sciences, Engineering, and Medicine's Roundtable on Aligning Incentives for Open Science. The following materials were developed to stimulate discussions at the November 5, 2020, workshop on Developing a Toolkit for Fostering Open Science Practices:

I. **Open Science Imperative**. This essay communicates the benefits of open science using approachable language.
II. **Open Science Signaling Language Template and Rubric**. These resources provide specific language that can be adapted and adopted to signal an organization's interest in open science activities at specific points of high leverage (e.g., grant applications, job postings).
III. **Good Practices Primers**. These concise guides offer policy makers a high-level overview of open sharing.
IV. **Open Science by the Numbers Infographic**. This infographic communicates the benefits of open science in a graphic form.
V. **Open Science Success Stories Database**. This database compiles research articles, perspectives, case studies, news stories, and other materials that demonstrate the myriad ways in which open science benefits researchers and society alike.

VI. **Reimagining Outputs Worksheet**. This table enumerates the range of research products stakeholders may choose to consider as they develop open science policies.

The toolkit is primarily intended to assist university leadership, academic department chairs, research funders, learned societies, and government agencies about how such a toolkit might be used, what additional materials are needed, and how such a toolkit should be disseminated for broad adoption. As a result of the workshop, a few sections in the Open Science Imperative and Good Practices Primers have been revised by the working group authors.

I. OPEN SCIENCE IMPERATIVE[1]

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This narrative communicates the benefits of open science using succinct, approachable language. One way to think about its possible deployment is to envision an academic administrator or senior leader at a philanthropy who has a vague notion that open science is something they should better understand. This piece, if successfully executed, will make the affirmative case as to why the open approach to the research endeavor is preferable to the status quo, and what the benefits to society will be if it is adopted at scale.

Over the last 20 years, the research community has grown increasingly interested in and supportive of open science activities. Open science encompasses a range of individual, institutional, and community efforts to broaden access to research outputs. This increased accessibility facilitates better collaboration and outcomes as a function of collective intelligence. By prioritizing shared discovery over individual and institutional agendas, open science practices are spurring the knowledge economy, generating broad social and public benefits, strengthening cultural values for scientific literacy and education, and improving public policy and democracy (Tennant et al., 2016; Zuccala, 2010). Despite the benefits of open science, individual researchers face numerous barriers that are restricting broad uptake of these practices. The current credit and reward systems disincentivize information sharing in favor of siloed, noninclusive modes of knowledge production. Significant, coordinated support within and across research stakeholder groups is necessary to change these incentives to realize the benefits of open science. This white paper, prepared in conjunction with the National Academies of Sciences, Engineering, and Medicine's Roundtable on Align-

[1] The views expressed are those of the authors and do not necessarily reflect the official policies or positions of their employing organizations.

ing Incentives for Open Science, briefly sketches the current state of open science, contrasts the diminishing returns of the traditional scientific model with the advantages of emergent open science practices, and suggests possible measures that organizations can individually and collectively undertake to shape the future of research and discovery.

THE STATE OF OPEN SCIENCE

Open science has been conceptualized in philosophical and ideological terms as an affinity for open flows of information to facilitate innovation for the betterment of society (Gold, 2016), but it is most frequently used as an umbrella term to describe active efforts to reduce the barriers to information access for researchers and the public. A commonly used definition of open science is "the idea that scientific knowledge of all kinds should be openly shared as early as is practical in the discovery process" (Nielsen, 2011). Although varying conceptualizations and definitions of open science exist, there is general agreement on the practices that support it, such as open access publication, research preregistration, open access to data and materials, and development of open source software (Berg and Niemeyer, 2018; Gold, 2016; Gold et al., 2019).

Increased adoption of these mutually reinforcing practices by institutions and especially by individual researchers has created a momentum behind open science. This momentum is reflected partly by the choices that researchers make regarding how their data are shared. In one survey, the number of researchers who reported making their data openly available increased from just over 55 percent to 64 percent between 2016 and 2018. From before 1990 through the 2010s, the percentage of researchers who were unaware of the license under which they made their data openly available decreased from 71 percent to 54 percent. During the same time, the percentage of respondents who would feel motivated to make their data openly available for co-author credit increased from 7 percent to 27 percent (Digital Science and Figshare, 2018, 8, 13).

The rise of open access as a widespread publishing practice also indicates greater uptake of open science principles and values. An analysis of 70 million articles published between 1950 and 2019 determined that at least 31 percent of all scholarly publications are available as open access and that the proportion is growing. The same analysis indicated that, given existing trends, 70 percent of all article views will be to open access papers by 2025 (Piwowar et al., 2019). This trend appears to be driven by the values held by researchers: "Over 90 percent of OA [open access] authors published this way because of the principle of free access" (Swan and Brown, 2004, 5) and because of "their perceptions that these journals reach larger audiences, publish more rapidly and are more prestigious than the toll-access (subscription-based) journals that they have traditionally published in" (Swan and Brown, 2005, ES 1). This momentum toward the open sharing of research papers is further underscored by the spectacular flourishing of preprints, with both readership and authorship growth near 100 percent year-on-year (Abdill and Blekhman, 2019).

These data indicate that although open science practices have been adopted by an increasing number of researchers, a large share of researchers remain either unaware of the benefits of these practices or find that the barriers to adoption (including time, resources, lack of clear guidance, and ambiguous incentives) are significant. Enhanced researcher awareness and adoption of open science approaches, combined with proper institutional support and better alignment of credit/reward systems, holds the potential to realize greater knowledge diffusion; improved efficiency, transparency, and interdisciplinarity of scientific exploration; and a more robust, accessible, and replicable body of research (Spellman et al., 2018; Tennant et al., 2016).

THE BENEFITS OF OPEN SCIENCE

Communicating the advantages of open science to researchers and the broader public is essential to greater uptake of these practices. Open science offers an array of benefits across five domains:

1. ***Supporting the growth of the knowledge economy.*** By facilitating freer flows of information among scientists, research institutions, and firms, open science practices can accelerate the discovery process and commercialization of scientific research. The inherently transparent nature of open science also makes testing the reproducibility and replicability of scientific research substantially more efficient.
2. ***Improving the integrity, reliability and transparency of scientific research.*** Science as a process operates with reproducibility as a core objective. Students are trained through replication exercises and scientists are expected to describe their work in ways that facilitate replication. Open science practices make the processes of

science more transparent, which, in turn, makes scientific findings easier to test and to trust.

3. ***Generating social and public benefit.*** By lowering barriers to public participation in science, open science approaches allow social needs articulated by the public to inform a greater share of scientific research and enable citizens to make better-informed decisions.
4. ***Strengthening scientific literacy and education.*** By making scientific research freely available to the public, open science enables nonscientists to become more familiar with scientific methods and encourages greater layperson interest in applying a rigorous, inquisitive approach to their engagement with the world and the pressing issues of the day.
5. ***Improving public policy and democracy.*** By encouraging greater transparency in research and availability of research products, open science allows policy makers and the public to be more informed about research that can be used to shape policy and promote civic action.

Numerous research projects and platforms have realized the benefits of open science approaches, sometimes across all five of these domains, including the following:

- **The Human Genome Project,** completed in 2003, was carried out with an explicit commitment to open science. Participating researchers pledged to make their discoveries available online within 24 hours and provide unrestricted access to information in real time. As a result, the project's public-domain gene sequences generated an estimated 30 percent more genetic diagnostic tests than genes that were first sequenced by private firms and then restricted as intellectual property. The myriad of public and private economic benefits created by the Human Genome Project (estimated at $965 billion and nearly four million jobs between 1988 and 2012; Tripp and Grueber, 2011) have established it as a model for the effective use of open data, providing a picture of what the future of science and innovation could look like with greater adoption of open science practices (SPARC, n.d.).
- The **Group on Earth Observations (GEO)** is a global network of more than 100 national governments and more than 100 par-

ticipating organizations that enables the collection and sharing of atmospheric, oceanic, and terrestrial data and information to facilitate better decision making and policy formulation. GEO's Global Earth Observation System of Systems (GEOSS) portal was designed according to best practices in open science to facilitate open, coordinated, and sustained data sharing to advance the United Nations 2030 Agenda for Sustainable Development, the Paris Agreement, and the Sendai Framework for Disaster Risk Reduction. In addition to enabling communication between researchers and governments, "data products and information derived from GEO data can be useful for individuals to better understand the environment in which they live and work, and protecting the health of their family, and better educating themselves, and through the positive results of many other generative and even serendipitous applications" (Benkler, 2006; Mayo and Steinberg, 2007; NRC, 2009; and Zittrain, 2006; cited in Uhlir, 2015, 13).

- **The Lab @ DC** is a unit within the Washington, D.C., mayor's administration that works to design public policy and program interventions for the city. The Lab @ DC uses the Open Science Framework to share their methodology, analysis, and evaluations of municipal programs, utilizing transparency to allow their projects to be reproduced and replicated by other community groups. Projects that have been undertaken by this group span from transit, housing, and public safety to customer service and economic prosperity (The Lab @ DC, n.d.).
- **Symbiota** is an exclusively web-based open source content management system that integrates natural history collections and other biological community knowledge and data into a network of databases and tools to increase knowledge of biodiversity. Since 2012, 73 percent of projects funded by the National Science Foundation's Advancing Digitization of Biodiversity Collections have used Symbiota. The platform now hosts 37 million records from 766 universities, museums, and research organizations, including linkages to images, tissues, DNA sequences, and taxonomic and ecological information (Symbiota, n.d.). Importantly, Symbiota's software design philosophy and implementation was driven by its "*user community*—e.g., collections managers, taxonomists, ecologists, data entry personnel, programmers, informaticians, and students" (Gries et al., 2014). Symbiota is freely available to researchers and the public.

- **Global Open Data for Agriculture and Nutrition (GODAN)** is an initiative of the U.S. Department of Agriculture and U.S. Agency for International Development that promotes open data sharing to increase global access to information about agriculture and nutrition. Leveraging data input from a partner network of more than 700 private- and public-sector, nonprofit, and academic organizations, GODAN aims to inform and improve daily decision making for farmers and consumers, with the goal of developing solutions to global hunger (Adams, 2018).
- **Microreact** is a free, real-time tool for visualizing and tracking outbreaks of diseases such as Ebola and Zika, as well as antibiotic-resistant microbes. Developed through a collaboration between researchers from the Wellcome Trust Sanger Institute and Imperial College London, Microreact allows any researcher in the world to upload information on disease outbreaks via its web browser, which can be shared and visualized through Microreact's cloud-based system. Microreact also integrates data submitted for publication in the journal *Microbial Genomics* to encourage greater data availability and access (Wellcome Trust, 2016).
- The **California Policy Lab** is a nonprofit based at the University of California, Los Angeles and Berkeley, that partners with state and local governments to solve social issues, including homelessness, poverty, crime, and educational inequality (California Policy Lab, n.d.). The California Policy Lab utilizes the Open Science Framework and has established data-sharing agreements with more than a dozen county agencies in Los Angeles, Sonoma, and San Francisco covering "medical, mental health, criminal justice, social service, and homeless management information systems" (California Policy Lab, 2018). The lab recently received a $1.2 million grant to expand to all University of California schools and partner with more public agencies to conduct policy-relevant research and overcome data silos.
- The **International Virtual Observatory Alliance** is an open platform enabling astronomers, educators, and the general public to discover, access, and integrate open data from worldwide (including in orbit) observatories. It links together the vast astronomical archives and databases around the world, together with analysis tools and computational services, into a single, integrated

facility. From its inception in 2002 through late 2020, the Virtual Observatory data have powered more than 2,300 scholarly papers,[2] covering the entire electromagnetic spectrum, from gamma-rays to radio waves.

- The **COVID-19 Open Research Dataset (CORD-19)** is an open collection of scientific articles and preprints related to COVID-19 and historical coronavirus research. The dataset can be text mined and analyzed using artificial intelligence and natural language processing to generate new insights into combatting the virus. The dataset was downloaded more than 200,000 times in the first 3 months after its release (Wang et al., 2020). This is one of several examples of open science's centrality in rapidly addressing this era's most critical public health challenge.

OPEN SCIENCE AND THE STATUS QUO

Historically, academic research environments have incentivized competition between individual researchers, which stymies collaboration and leads to the hoarding of knowledge. These dynamics persist as a function of the pursuit of "excellence" by research institutions, which results in the widespread usage of metrics that decrease transparency and collaboration. For example, measuring success by the number of patents filed and industry spinoffs launched leads to the safeguarding of intellectual property by researchers rather than the sharing of this information with external organizations that can increase the possibility of taking a product to market. Likewise, when academic departments measure their success by the volume of research citations and grant tenure to researchers who are cited most frequently, researchers are pressured to be the first to publish their findings and often operate in isolation, rarely venturing out of their respective research programs and communities (Heenan and Williams, 2018). Researchers become understandably hesitant to make their data and findings openly available out of fear of being "scooped" by other researchers (Berg and Niemeyer, 2018). Although competition between institutions and individual researchers may have been adequate to drive discovery in the 20th century, the "explosive sophistication" of science and engineering fields, in particular, has made it impossible for a single individual to be an

[2] Data accessed from the SAO/NASA Astrophysics Data System, October 16, 2020.

expert in multiple specialties or even a single subfield. Effective knowledge production now demands teams of researchers with diverse knowledge and skills to facilitate ongoing discovery (Brooks, 2010). Greater collaboration, rather than being an aspirational ideal that might produce better outcomes under the right circumstances, has now become a necessity to contend with the extreme specialization of knowledge production and ensure that discovery continues apace.

Open science practices, in contrast to traditional models of knowledge production, emphasize that open, transparent, and collaborative research dissemination practices more properly balance collective, institutional, and individual benefits. Open science represents a positive evolution of the research endeavor along three dimensions:

- ***Collaboration drives innovation with the potential for broad social impact.*** Open science approaches can reduce barriers between researchers and other stakeholders, including the public (e.g., by better informing and directly involving patients in biosciences) (Gold, 2016). By making data openly accessible between researchers and the public, open science can provide greater opportunities for interdisciplinary, collaborative research across institutions worldwide (Uhlir, 2015). Heightened collaboration can also lead to dynamic new knowledge hubs and remove barriers to upstream research and technology transfer (Gold, 2016).
- ***Greater efficiency and speed.*** Open data practices also drive efficiency by enabling real-time, data-driven decision making (Adams, 2018; SPARC, n.d.). The sharing of data reduces transaction costs; increases reproducibility and reuse of data; decreases redundancy; and drives greater transparency, heightened efficiency, and accelerated sustainable innovation (Gold, 2016; Gold et al., 2019; Tennant et al., 2016).
- ***Replicability enhances trust and research quality.*** By enhancing researchers' ability to verify results, open science practices help to build trust and goodwill among researchers and enhance the legitimacy of research (Popkin, 2019; Uhlir, 2015).

THE ROLE OF RESEARCH STAKEHOLDER ORGANIZATIONS

Open science has been largely pioneered by individual researchers who believe the benefits of this approach—to their work, to the shared understanding of a problem space, to their discipline, and to society—outweigh the reputational benefits that may be derived from the older, competition-based models of knowledge production. However, many researchers continue to face strong disincentives for engaging in open science practices, especially early-career scholars, who face the greatest pressure to conform to the traditional modes of credit and recognition that can lead to tenure. The wider uptake of open science, therefore, requires the organizational stakeholders responsible for reward systems—institutions, government agencies, and philanthropies chief among them—to establish new incentives and processes that prioritize open science activities. Because the competition-based incentives that motivate researchers reflect institutional prerogatives to demonstrate excellence vis-à-vis other institutions, institutions must also convene to identify new approaches toward facilitating interinstitutional collaboration and collectively address external barriers to open science.

Fortunately, the values that underpin open science—such as inclusiveness, collaboration, social impact, and scientific literacy—are mutually reinforcing to the missions of the research institutions, agencies, and funding organizations that support scientific research. Forward-thinking organizations have already begun to implement incentives for open science practices that provide a model for others to follow, which have taken several forms, including the following:

1. ***Creating supportive environments.*** The Tanenbaum Open Science Institute (TOSI) at the Neuro (Montreal Neurological Institute-Hospital) was designed as a "living lab for Open Science" to achieve the goals of accelerating discovery in neuroscience through collaboration, developing global best practices, and delivering innovative treatment to benefit patients afflicted by neurological diseases. TOSI supports four Open Science initiatives, including a biologic imaging and genetic repository, an open research platform, several open neuroinformatics platforms, and an early-stage drug discovery unit that collaborates with academia and industry partners (Gold, 2016; Neuro, n.d.).

2. ***Incentivizing open access publishing.*** The Bill & Melinda Gates Foundation and the Wellcome Trust, which funded $1.3 billion and $1.2 billion in global health research, respectively, joined a consortium of 11 European funding agencies that require all funded research to be free immediately upon publication. This incentive effectively requires scientists to publish papers in open access journals rather than those that charge subscriptions (Stokstad, 2018).
3. ***Awards for Open Science innovation.*** In 2017 the National Institutes of Health, Wellcome Trust, and the Howard Hughes Medical Institute hosted the Open Science Prize competition, leveraging public input to determine award finalists (NIH, 2017).

These examples represent the kinds of new incentives critical to instantiating the cultural shift necessary for sustained uptake of Open Science. In designing new incentives, research organizations and funders may also consider topics such as advancing the theory and practice of Open Science; how hiring decisions may contribute to cultures supportive of Open Science; and how funding mechanisms can be evolved to encourage open access publishing, data archiving and sharing, preregistration, and collaboration. The National Academies' Roundtable on Aligning Incentives for Open Science aims to encourage exploration of these topics and a wide range of possibilities for using incentives to realize the full potential for scientific research as a catalyst for discovery, economic growth, and societal benefit.

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